FEBRUARY 1955

THE WELDING JOURNAL

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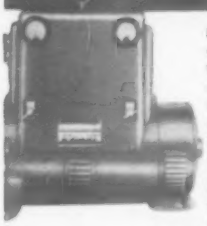

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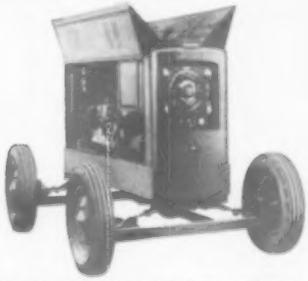

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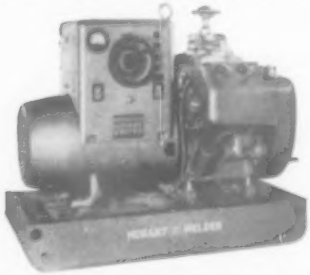

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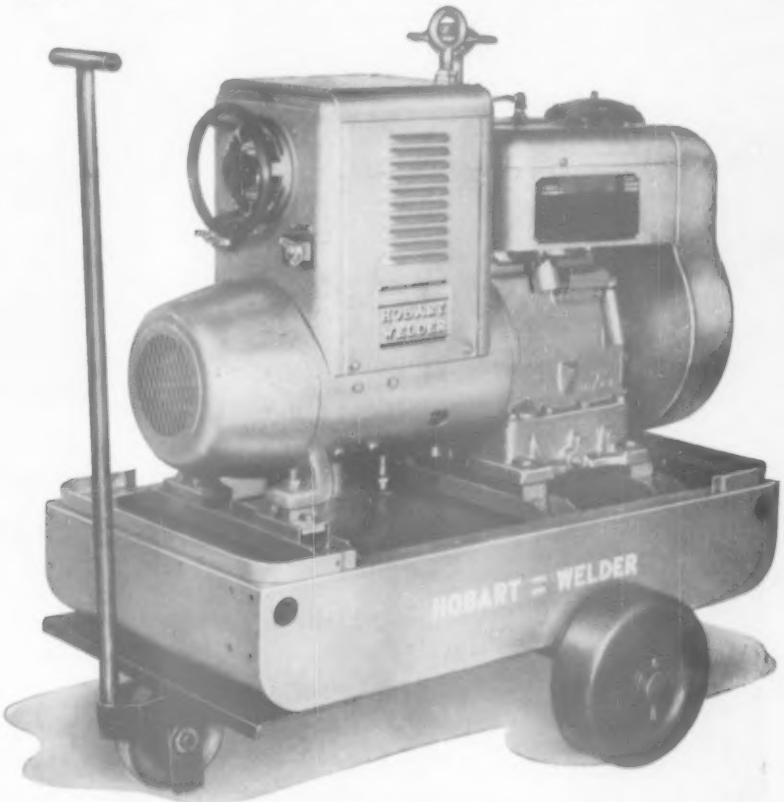

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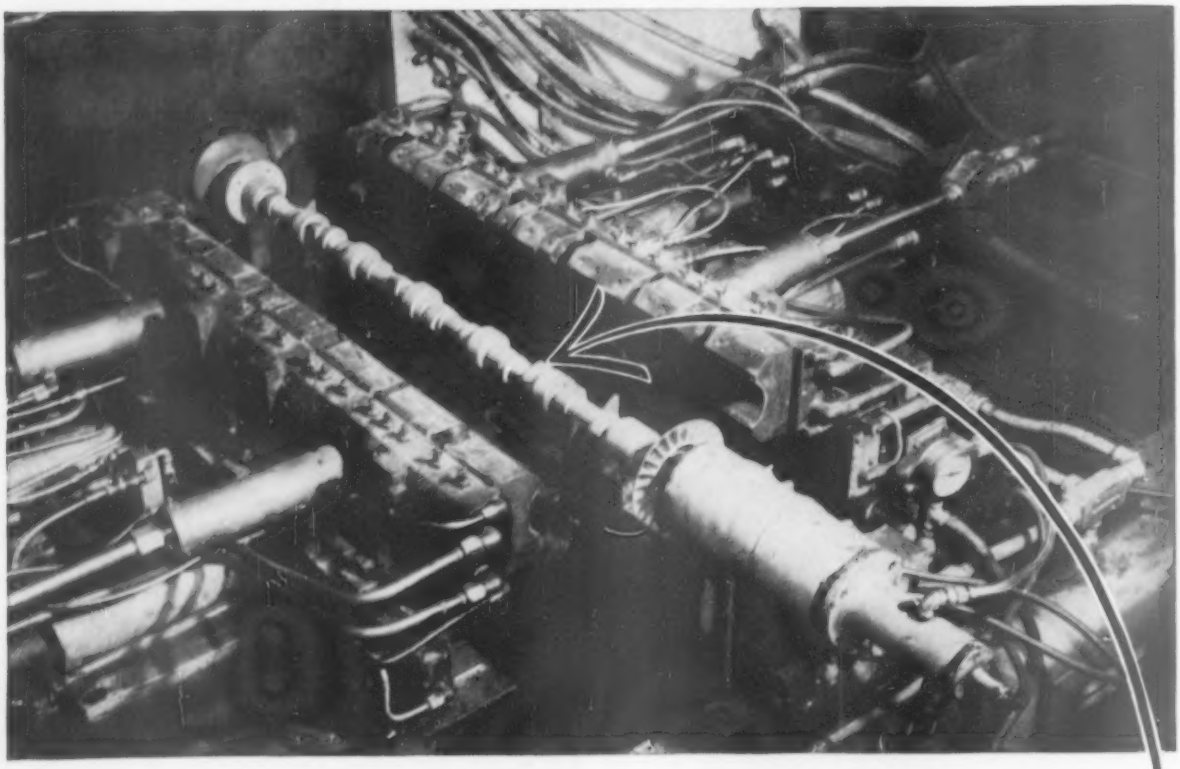

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The AMERICAN WELDING SOCIETY adheres to the principles established in 1919 by its Founders, concisely summarized in its simple motto—"To advance the science and the art of welding." Properly interpreted those words imply that AWS is dedicated to furthering the use of welding by means classified as educational, technical, scientific or professional. In the thinking of responsible industry and the professions, it has properly promoted welding by encouraging welding research, compiling valuable welding knowledge, recording the experience of the world's welding authorities, and disseminating such through its various publications, codes, standards and Section and National meeting lectures.

AWS will always oppose undue restrictions on welding. It must always seek ways and means to improve quality. But its standing and the unalterable factors of safety will not permit its taking short-cuts without first exploring the path for possible pitfalls. It can never compromise on quality. It cannot subscribe to the premises that any or all steel materials used are good; that high inspection standards need not be maintained; that inspection of welds is not necessary; nor that any or all welds are good.

AWS gives consideration to every pertinent viewpoint and suggestion. It welcomes constructive suggestions. It is as much aware of the essentiality of not being overrigid in specification and code writing as it is of its objectives—the universal recognition that welding is the logical means for the joining of metals, similar or dissimilar in structure, and that structures be properly designed for welded assembly.

Rules which guide—which indicate the safe proved direction—accelerate the speed of progress, even as a clear, properly engineered, adequately posted highway safely speeds the progress of transport. For example, today *all* pressure vessels are welded. Few other types of fabrication are as fortified with codes and standards as is that specific field of application and construction. Vessel fabricators know that by adhering to the rules they will produce a product which will not become a liability. Purchasers know that in buying a product so constructed, they are assured safety.

When a better plan for securing better welding is presented, AWS will support it. Meanwhile AWS is realistic in that it recommends regulations and codes which assure good welding. It provides—to the best of its ability and finances—training aids for the qualification of welders and the education of inspectors and supervisors, so that good welding and safe structures may be assured. It opposes undue restrictions on welding. AWS will continue to travel the clear straight road.

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THE MACRO ETCH SYSTEM OF EVALUATING QUALITY OF RESISTANCE WELDING

Weld quality in multiple thickness combinations of stainless steel evaluated by correlating nugget sizes and tensile-shear values gathered from production data

BY D. O. SAMUELSON AND F. G. HARKINS

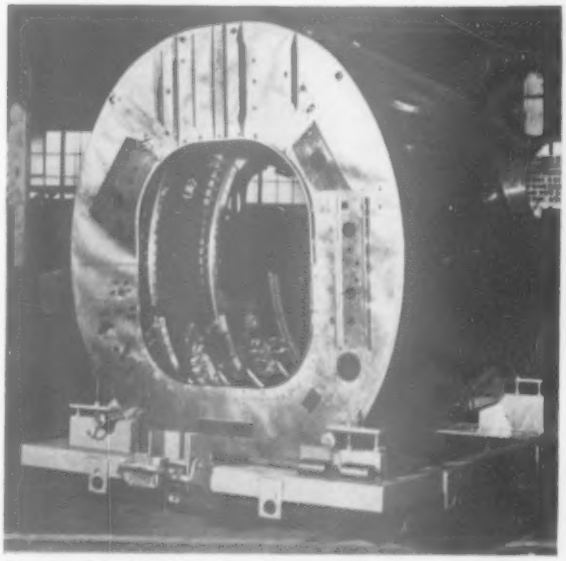


Fig. 1 Exterior view of engine nacelle

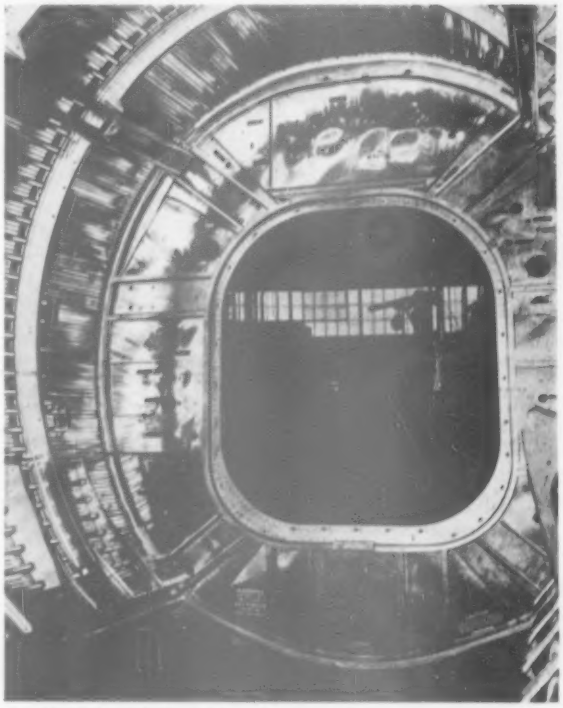


Fig. 2 Internal view of engine nacelle

Introduction

During the past fifteen years, resistance welding has gained the respect of most aircraft manufacturers as being an acceptable method of joining structural members of air frame and engine components. Much data and many specifications have been published and are in daily use. Quality control procedures have evolved, and ideal or foolproof methods for analyzing resistance welds are constantly being sought.

The production part in the flying airplane is the best test of the results of the testing and precautions taken on the production floor and in the laboratories of the manufacturers.

Many structural parts, which are resistance welded, are flying in almost every commercial and military aircraft today.

Quality control procedures have long been a controversial subject in resistance welding. The purpose of any quality control procedure is to insure the production of parts to the minimum acceptable standard. In aircraft fabrication, there are two basic requirements. The first is to produce sound, usable parts according to the engineering drawing, and the second is to produce parts to the applicable specification. To the design and production engineers, the manufacture of usable parts is of paramount importance, while to the quality control personnel, the production of parts to specification assumes the foremost position. Objectively, there is no real difference in the aims of these

D. O. Samuelson and F. G. Harkins, Welding Engineer and Chief Welding Engineer respectively, are with the Solar Aircraft Co., San Diego, Calif.

Presented at the AWS Thirty-Fifth National Fall Meeting held in Chicago, Nov. 1-5, 1954.

Table 1—Cost Analysis Table—Weld Coupon Usage

Explanation	*January*	*February*	*March*	*April*	*May*
Test strips used	109,223	129,825	140,775	159,875	285,596
Average No. of tests	36,408	43,275	46,925	53,292	95,199
Test/direct labor hours	2075.6	2466.7	2674.7	3037.6	5426.3
Test/inspection labor hours	1413.4	1680.3	1821.6	2068.5	3696.0
Test/total hours	3489.0	4147.0	4496.3	5106.1	9122.3
Total labor costs	$5,198.61	$6,179.03	$6,699.49	$7,608.90	$13,592.23
Total material costs	10,084.47	11,985.44	12,996.35	14,759.66	26,366.22
Subtotal Cost	$15,283.08	$18,164.47	$19,695.84	$22,368.56	$39,958.45
Less: Scrap credit	1,256.06	1,492.99	1,618.91	1,838.56	3,286.35
TOTAL COST	$14,027.02	$16,671.48	$18,076.93	$20,530.00	$36,672.10

groups. Both groups are interested in the production of low-cost, usable, salable items. In view of the many certifications, qualifications and high cost of quality control procedures which are required by Air Force, Army and Navy, it is debatable that resistance welding is an economical method of joining materials. A major cost in any resistance welding program is that of the quality control system. The initial cost of the welding machine is high, but if this cost is amortized over the normal life of the equipment, the cost is reasonably low. If the cost is calculated on the basis of the number of parts which may be produced on a machine, the equipment cost becomes infinitesimal. The quality control procedure, however, is a never-ending expense.

Discussion

Table 1 shows an analysis of some of the costs involved in the operation of the quality control procedure in the San Diego plant of the Solar Aircraft Co. for the period January 1952 to May 1952. It is apparent that the production schedules were increasing during this period. It will be seen that in May of 1952 the direct labor cost at $1.49/hr for the operation of the control system was $13,592.23. Material cost was $26,366.22. Actual cost per test is ($36,672.10 ÷ 95,199) about $0.40. There are approximately 150 qualified welding machines involved in this study. No administrative expenses or burden rates are reflected in these figures. Is this expenditure necessary? If the process control system prevents a failure of an airplane component in service, the cost of the system is probably justified. If the process control system allows the production of substandard parts there must be something fundamentally wrong with the system.

Most existing resistance welding specifications are based on two thickness combinations with qualifications regarding maximum ratios of material thicknesses of two to one or three to one. Some of these specifications refer to multiple thickness joints with qualifying statements such as, "When more than two sections of material are joined by each spot weld in a production part, representative test specimens shall be welded in such a manner that the welds may be tested at both of the outer interfaces and at any other interfaces at which the production weld will be stressed," or "The minimum nugget diameter shall apply separately to each weld between each pair of adjacent sheets." Such specifications thereby restrict the minimum strengths or areas of individual welds in multiple thickness joints, but it is readily seen that it would be unrealistic to place a maximum value on this type of joint. Therefore, all multiple thickness joints must be considered in respect to one structural section of the joint and the balance of the weld joint must be accepted regardless of the weld size and strength value, providing the nugget shape is acceptable and the internal quality standards are met. Thus, any multiple testing after the initial standard for a single joint is set seems useless. Nugget size, shape and internal quality, as examined by macroetch, provides all the necessary information to completely analyze the joint for production acceptance.

On this basis, Solar Aircraft Co., San Diego, uses the macroetch inspection system extensively as a production inspection procedure. This does not imply that tensile testing is not used in our plant. Standard procedures for qualification of machines and certification of welding schedules are used in compliance with the MIL 6858 specification. In production three single-spot specimens are welded and tensile tested at the start of each shift. From this point on, production inspection procedure consists of macroetch tests at the start of each shift, or at the start of each job, upon replacement of electrodes, at intervals of not more than one hour during the run, and at the completion of each job.

Typical Application

A significant major component which lends itself to analysis of production procedures and on which much production data are available is the Lockheed P2V engine nacelle manufactured by Solar Aircraft Co. in San Diego. This unit has been in production for the past two years and much data have been compiled and tabulated. We have selected, for presentation in this paper, a portion of the multiple thickness data from which conclusions can be drawn and trends appear evident.

Figure 1 is an external view of the assembly mounted on the shipping dolly. The entire assembly is resistance welded and is primarily made up of Type 302 stainless steel components in gages from 0.010 to 0.063

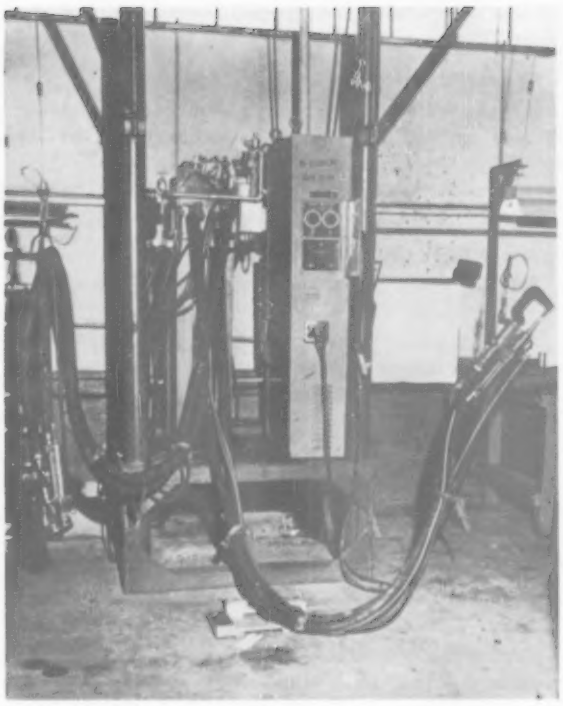


Fig. 3 Portable welding equipment

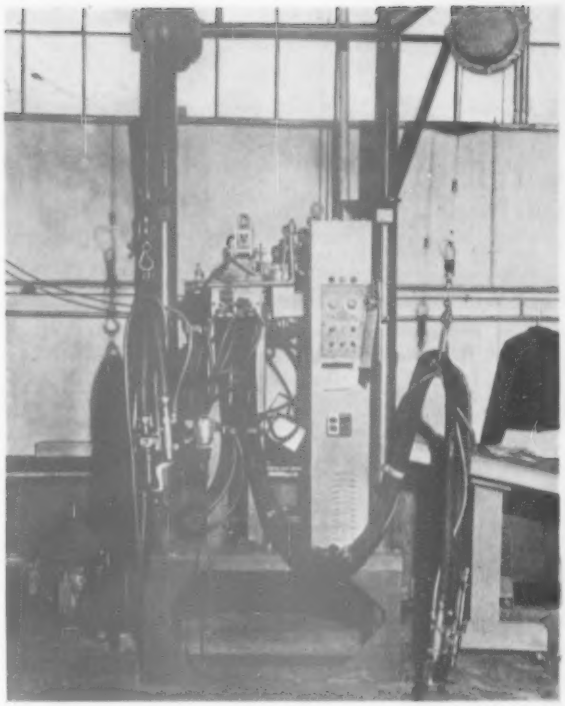


Fig. 4 Portable welding equipment

in. This photograph shows clearly some of the external doublers and channels on the forward firewall and some of the spot welds which number in the tens of thousands.

Figure 2 illustrates a portion of the internal structure. Note the longitudinal stringers which are of 0.012-in. full hard stainless steel. These hat section members are roller spot welded $^3/_8$-in. center to center in the subassembly stage of fabrication. Also of interest is the interior structure of the firewall showing the many channel and doubler components which are spot welded on pedestal type spot welders.

Most of the subassembly operations are accomplished on standard spot and seam welders which are all single-phase fully synchronous controlled machines.

Due to the complexity of construction, a portion of the subassembly and all of the final assembly of this unit are accomplished on portable spot-welding equipment. Figure 3 illustrates one of 11 gun installations which operate 21 specially designed portable guns for this fabrication. The transformers are all 100 kva with an 8-step tap switch. The control panels are all fully synchronous control with phase shift heat control. The gun units are all hydraulically operated and were designed to operate at 1500 to 2000 lb tip force. The entire unit has been combined into one integral machine with panel, transformer, booster, swinging gun booms, cables, hydraulic lines, electric hoists, and guns mounted on a single base which can be moved without complex disassembly or costly maintenance changes. The guns shown in Figs. 3 and 4 are those which make the welds which are analyzed in this report.

Production Data vs Laboratory Data

All of the data which are analyzed in this report were gathered from specimens which were made as a standard production procedure. The values recorded were taken by production inspection personnel on individual production runs. Therefore, the data presented are realistic and representative of actual operating practice.

This process of assimilating information from production data creates several problems in analysis which do not occur in normal laboratory practice.

The most aggravating problem involved is the scatter or wide range of values of nugget sizes and tension shear values. Production procedures call out a specific minimum value for nugget size and tension shear value but do not specify a maximum value in either case. Therefore, in production practice the problem is to exceed these minimum values in all cases. Under laboratory conditions a target value would be established and an arbitrary range for either value would be held, with analysis of the second variable being the product of the test data.

A secondary problem involved in an investigation of this type is the lack of precision in preparing and analyzing the specimens. Here again the production analyst is looking for a minimum value without critical examination of values over the minimum.

A third significant variable is the sheet thickness of the test specimens. Normal operation permits variations of $\pm$ 10% of the nominal stock thickness. Laboratory testing would recognize this factor and eliminate or confine this variable to a much narrower range.

The fourth significant variable is the material con-

Fig. 5 Photomacrograph of spot weld in 0.016, 0.025-, 0.025-in. thick sheets of type 302 stainless steel. X 12

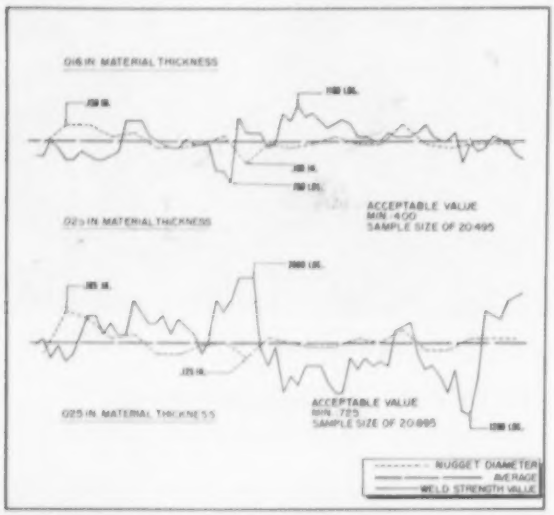


Fig. 6 Nugget diameter—tensile shear value graph; 0.016-, 0.025-, 0.025-in. thick sheets of type 302 stainless steel

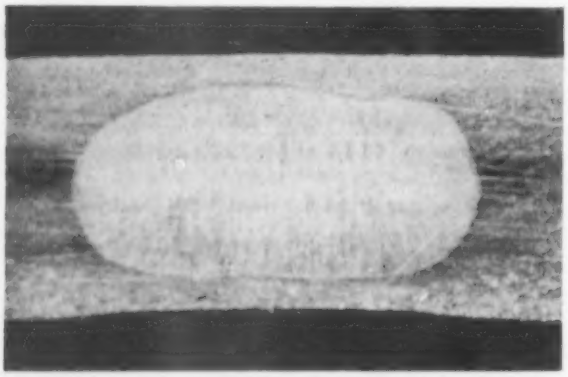


Fig. 7 Photomacrograph of spot weld in 0.050-, 0.016-, 0.025-, 0.032-in. thick sheets of type 302 stainless steel. X 12

dition. The specification AN-QQ-S-757 to which the material is purchased establishes 150,000 psi minimum tensile strength; no maximum value is specified. Tests in our laboratory have shown strengths of over 200,000 psi. As is generally recognized, the higher the tensile strength of the material, the greater will be the tension shear value. The nugget size may remain the same. All specifications recognize this phenomenon.

Data Analysis

The photomacrograph shown in Fig. 5 is 0.016–0.025–0.025 Type 302. Note the weld symmetry and the adequate penetration into the outer sheets.

The weld schedule for this joint is as follows:

12 cycles weld time.
600-lb force at the electrodes.
RWMA Class III upper electrode with $^3/_8$-in. face, 6 in. radius.
RWMA Class II lower electrode with $^5/_8$-in. face, 12 in. radius.
Approximately 5100 amp current.

Figure 6 is a graphic representation of the previous photomacrograph. The top graph represents measurements of the 0.016–0.025 combination. Sample size of 20 tension shear value is 495 lb. Minimum recorded value is 780 lb. Nugget range is from 0.100 to 0.150. The largest nugget diameters are not associated with the highest tension shear values for reasons noted previously. The lower graph in Fig. 6 represents the nugget sizes versus the tension shear values of the 0.025–0.025 section of the joint. Required tension shear value for "average of 20" is 895 lb. minimum recorded value is 1280 lb. Maximum recorded value is 2000 lb. Nugget range is 0.125–0.185 in. Highest tension shear values are not associated with largest nugget diameters due to the extraneous factors noted previously.

Figure 7 is a photomacrograph of a four thickness pile up of 0.050–0.016–0.025–0.032 Type 302 stainless steel. Penetration, weld structure, and shape requirements have all been met.

The weld schedule for this joint is as follows:
14 cycles weld time.
1000-lb force at the electrodes.
RWMA Class II electrodes with $^7/_{16}$-in. face, 8 in. radius.
Approximately 6000 amp current.

Figure 8 represents the results of data gathered from the production joint shown in Fig. 7.

An interesting fact which is shown on this chart lies in the tension shear value of the 0.016 specimen. Here the average value is 2192 lb as compared to 999 lb average shown in Fig. 6. Average nugget size is 0.203 as compared to 0.128 on Fig. 6. Average nugget diameter for the 0.050–0.016 combination is 0.183 in. for an average tension shear value of 2185. Minimum nugget diameter is 0.130 in. Maximum nugget diameter is 0.225 in. Tension shear range is 1900–2540 lb. The possibility of a mathematical relationship between nugget diameter and tension shear value is clearly shown. The trend—that for 0.016 material, tension shear strength is a function of nugget size—is also indicated.

Figure 9 illustrates joints between a 0.012–0.020–0.032–0.025 combination. Note the slight porosity in this weld sample. This porosity is well within any

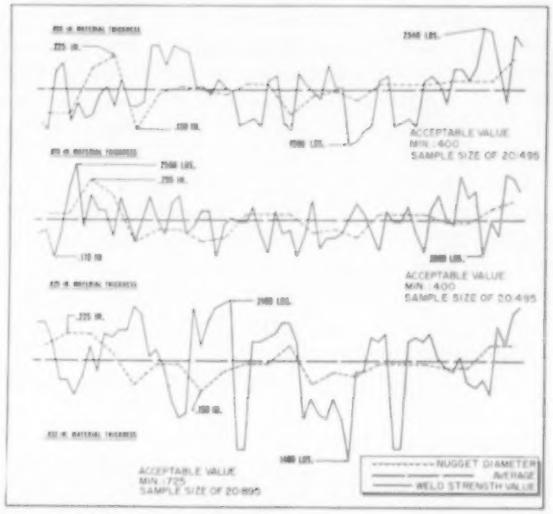


Fig. 8 Nugget diameter—tensile shear value graph; 0.050-, 0.016-, 0.025-, 0.032-in. thick sheets of type 302 stainless steel

applicable specification and is acceptable. The sheet separation shown is on the sample weld but is not evident in the production part due to weld spacing and sequence.

The weld schedule is as follows:

12 cycles weld time.
800-lb force at the electrodes.
RWMA Class III upper electrode with $^{3}/_{8}$-in. face, 4 in. radius.
RWMA Class II lower electrode with $^{5}/_{8}$-in. face, 12 in. radius.
Approximately 5400 amp current.

Figure 10 indicates the test results of the joint represented by Fig. 9. The trend shown in Figs. 6 and 8 is repeated here. Tension shear values vary in the range 500 to approximately 1100 lb. The standard of acceptability for this gage of material is 340 lb so that from a utilization standpoint the joints are acceptable.

Figure 11 shows a production joint in a 0.025–0.032–0.032–0.025 combination. Typical shape, penetration and quality standards are evident.

The weld schedule is as follows:

12 cycles welding time.
900-lb force at the electrodes.
RWMA Class II electrodes with $^{7}/_{16}$-in face, 8 in. radius.
Approximately 5100 amp current.

The graph in Fig. 12 represents the test results of the 0.025–0.032–0.032–0.025 weld joint. Variation in tension shear value is wide, but in no case does the lowest value approach the minimum acceptable value.

The weld shown in Fig. 13 is a 0.050–0.016–0.032–0.025–0.025 combination which shows evidence of minute porosity within the specification and illustrates the typical nugget shape, penetration and metallographic characteristics.

The weld schedule for this joint is as follows:

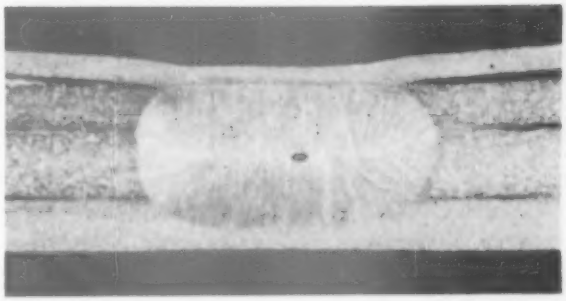


Fig. 9 Photomacrograph of spot weld in 0.012-, 0.020-0.032-, 0.025-in. thick sheets. X 12

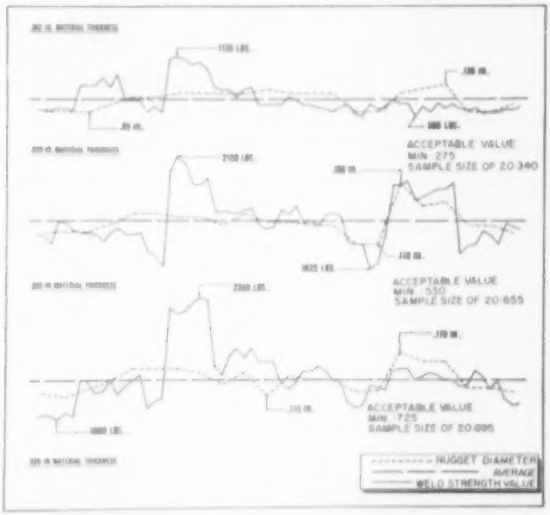


Fig. 10 Nugget diameter—tensile shear value graph; 0.012-, 0.020-, 0.032-, 0.025-in. thick sheets

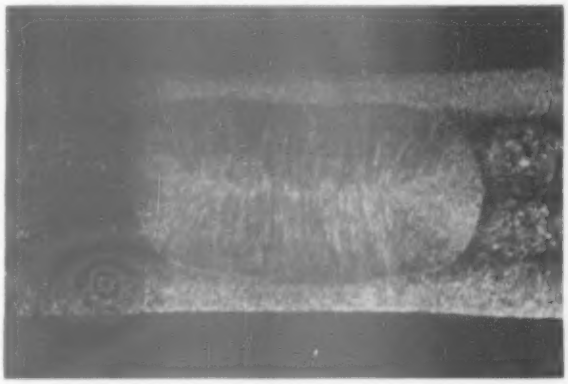


Fig. 11 Photomacrograph of spot weld in 0.025-, 0.032-, 0.032-, 0.025-in. thick sheets. X 12

14 cycles welding time.
1000-lb force at the electrodes.
RWMA Class II upper electrode with $^{5}/_{8}$-in. face, 12 in. radius.
RWMA Class III lower electrode with $^{7}/_{16}$-in. face, 6 in. radius.
Approximately 6500 amp current.

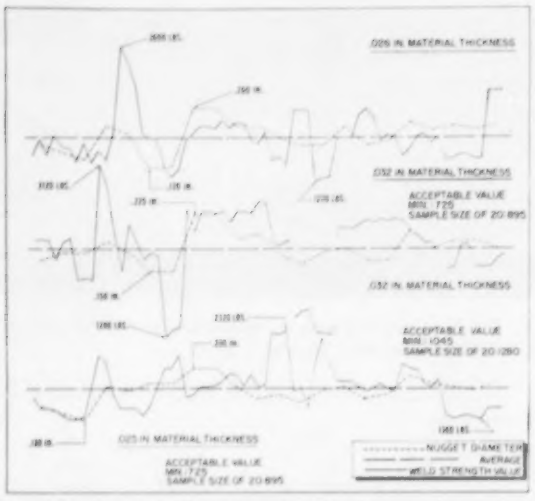


Fig. 12 Nugget diameter—tensile shear value graph; 0.025-, 0.032-, 0.032-, 0.025-in. thick sheets

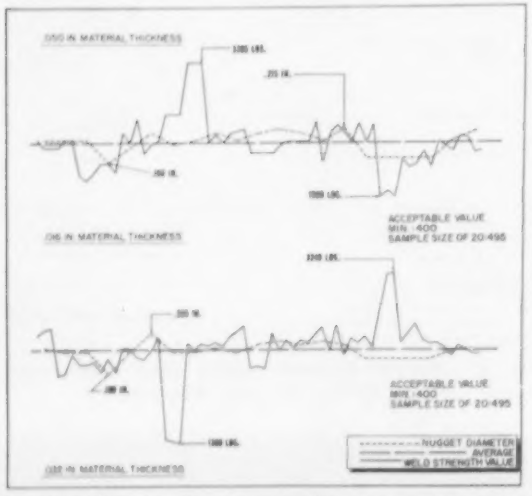


Fig. 14 Nugget diameter—tensile shear value graph; 0.050-, 0.016-, 0.032-in. thick sheets

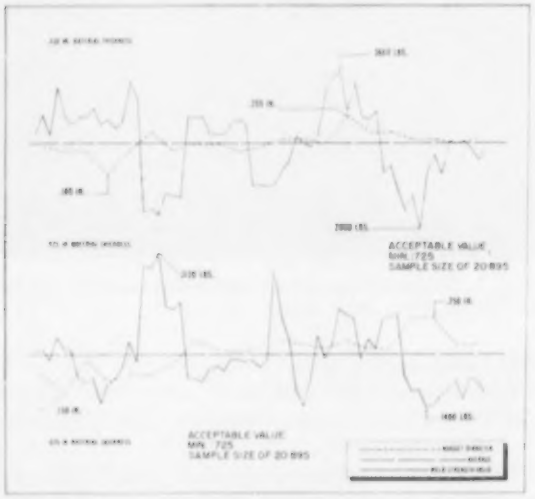


Fig. 15 Nugget diameter—tensile shear value graph; 0.032-, 0.025-, 0.025-in. thick sheets

To avoid using a smaller scale which would tend to distort visual interpretation of the data, Fig. 14 shows the results at the upper two interfaces of the joint in Fig. 13. Figure 15 illustrates the lower two interfaces of Fig. 13. The same trend of the relationship between nugget diameter and tension shear value is indicated.

Figure 16 illustrates a seven high pile-up which is a production joint of 0.040–0.036–0.025–0.032–0.032–0.050–0.070. The same weld quality is observed.

The upper two thicknesses are prewelded and the subsequent assembly is welded as follows:

6-cycle pulsation weld with 3 pulses, 3 cycles Off time.
1200-lb force at the electrodes.
RWMA Class II electrodes with $^1/_2$-in. face, 8 in. radius.
Approximately 12,000 amp current.

The relationship of the average of nugget diameters to the average of tension shear values is tabulated in Table 2. This tabulation definitely establishes the pattern. Deviations from the pattern occur in two places, but observation of the tabulation allows rationalization of the deviation.

To summarize the data contained in the charts: The material thicknesses which are shown are: 0.012–0.016–0.020–0.025–0.032-in.

In view of the fact that the data plotted on the charts were gathered from production applications under production conditions it is apparent that the law has been established.

Welds on multiple pile-ups will usually show higher tension shear values than simple welds. This is substantiated by the data on the charts and may be explained by:

1. The nugget sizes are usually larger in multiple thickness combinations.

2. Due to the increased stiffness of the multiple member, the tension shear test approaches a pure tension test.

Figure 17 shows the relationship between nugget diameter and tension shear value for all common gages of stainless steel whose ultimate tensile strength is 150,000 psi and higher. Source of this data is the American Welding Society *Recommended Practices for Resistance Welding*—1950 edition.

Study of this curve shows it to be formulated from empirical data. The value of y approximates a parabolic function which, of course, could be put in the form of $y = ax^2 + bx + c$.

There is an excellent practical reason for the curve

Fig. 13 Photomacrograph of spot weld in 0.050-, 0.016-, 0.032-, 0.025-, 0.025-in. thick sheets. ✕ 9

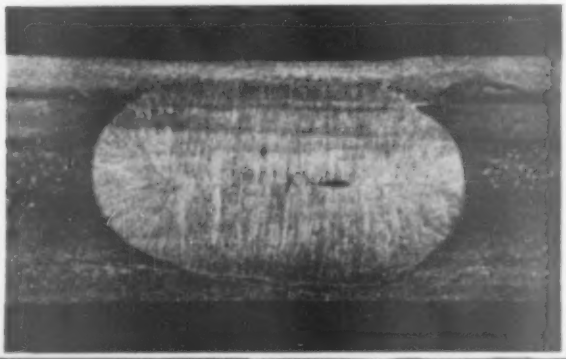


Table 2—Summary Table of Nugget Diameter—Tensile Shear Value

0.016		0.012		0.020		0.025		0.032	
Nug.	*T/S Value*	*Nug.*	*T/S Value*	*Nug.*	*T/S Value*	*Nug.*	*T/S Value*	*Nug.*	*T/S Value*
0.128	999	0.130	675	0.116	675	0.128	999	0.136	1395
0.183	2185	...	...	0.139	1531	0.136	1395	0.139	1531
0.210	2700*	...	...	...	...	0.146	1658	0.162	1702
0.220	2192	...	...	...	...	0.188	1919	0.170	1707
0.225	2500	...	...	...	...	0.203	2192*	0.181	2240
...	...	...	...	...	...	0.204	2052	0.188	1919
...	...	...	...	...	...	0.220	2020	0.220	2020

* Inside joint supported by thick members on each side.

becoming parabolic. This lies in the limitations of the welding equipment. According to the *Resistance Welding Manual*—1948 edition the optimum electrode size can be calculated from the formula $d = 2T + 0.1$, where d is the diameter of the electrode face; T, the thickness of material being welded; and 0.1, the constant expressed in inches.

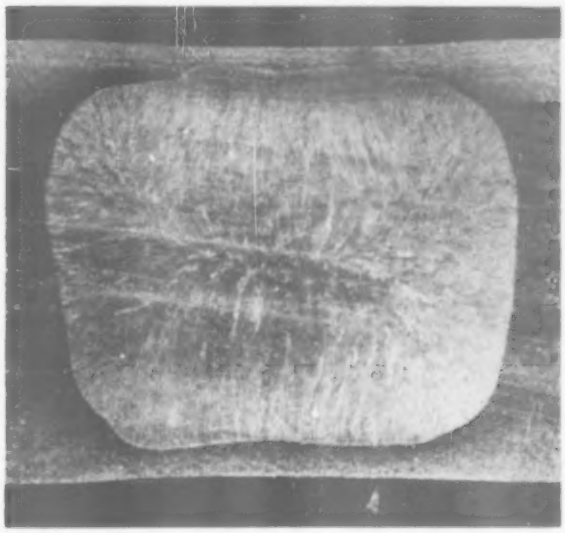


Fig. 16 Photomacrograph of spot weld in 0.040-, 0.036-, 0.025-, 0.032-, 0.032-, 0.050-, 0.050-in. thick sheets. ×9

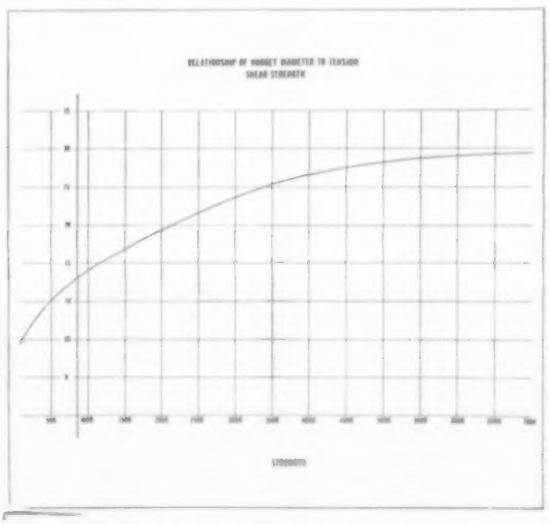


Fig. 17 Nugget size vs. tensile shear value graph

On very thin materials the diameter of the electrode could become so small that electrode shape could not be maintained in production. It is accepted procedure, therefore, to limit electrode diameter to not less than $^5/_{32}$ in.

Similarly, the curve levels off at the upper end of the scale for the reason that the electrode forces which are available from standard welding machines are not sufficiently high to maintain the required unit force level (psi) for nugget diameters larger than approximately 0.35 in.

For these reasons a strict mathematical interpretation of this curve is not recommended.

The curve does indicate a relationship between nugget diameter and tension shear value. As nugget diameters increase, tension shear values increase in the same manner.

Summary and Conclusions

From the foregoing discussion the following conclusions can be drawn:

1. Process control procedures for resistance welding are costly to maintain and a need for an effective nondestructive, low-cost, control system is essential to further advance the process in industry.

2. Existing specifications for resistance welding are diversified and should be consolidated and simplified.

3. Macroetch examination of welds in stainless steel is an approach to the problem and is one satisfactory production quality control procedure which is less costly to maintain.

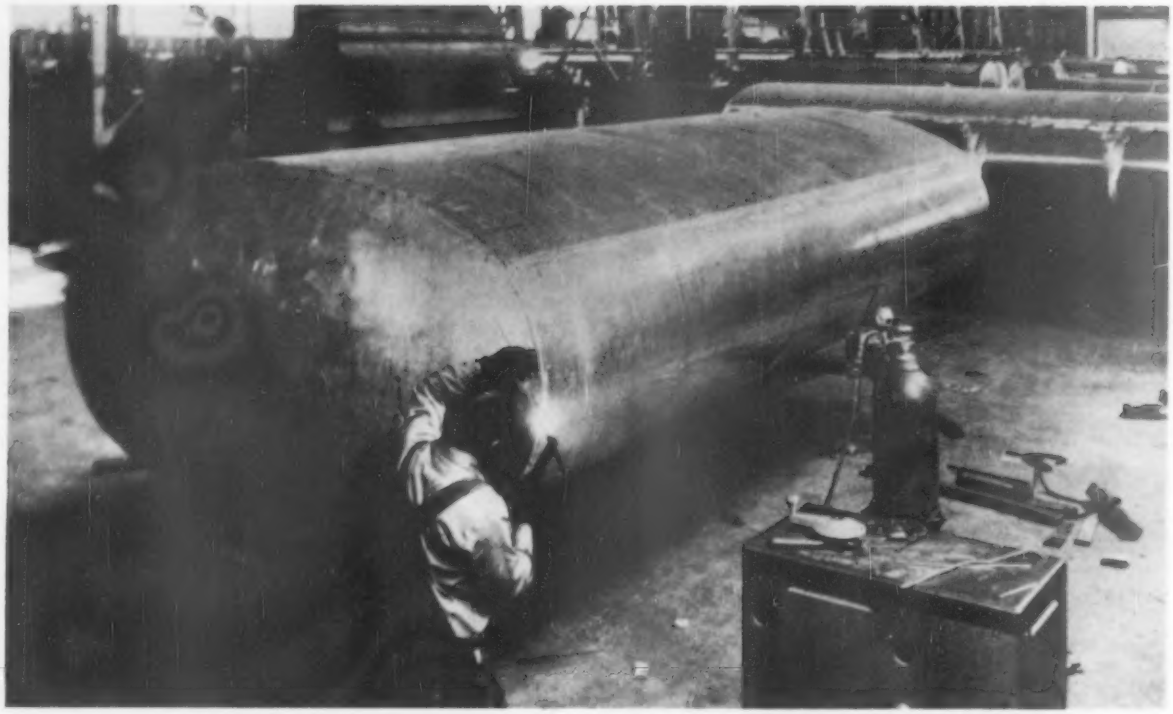
The following conclusions become evident in the use of such a procedure:

1. Under production conditions it is not possible to predict with precise accuracy the tension shear value from careful measurement of the nugget diameter.

2. Tension shear values of spot welds will be significantly higher in multiple pile-ups than in simple welds.

3. In holding within the specified nugget range the tension shear value cannot fall below the "average of 20" value of any existing specification.

4. Tension shear values are related to nugget diameters. The larger the nugget diameter the greater will be the tension shear value; although extraneous factors such as ultimate tensile strength, grain size and ductility will influence this relationship.



Tungsten arc welding of gasoline trailer tanks at Beall Pipe and Tank Corp., Portland, Ore. Tanks fabricated of 5086 (K186) alloy using 5056 (56S) filler wire

PROPERTIES OF WELDS IN AL-MG-MN ALLOYS 5083 AND 5086

Paper presents data on the mechanical, physical and welded properties of alloys 5083 and 5086 as compared to 2024, 5052 and 6061 alloys. Data includes tensile properties, hardness surveys, bend tests, radiographs and metallographic examination of typical specimens

BY L. A. COOK, S. L. CHANNON AND A. R. HARD

SYNOPSIS. This paper presents data on the mechanical and physical properties and weld characteristics of the two new aluminum alloys 5083 (LK183) and 5086 (K186)* and compares them by similar data to 2024 (24S), 5052 (52S) and 6061 (61S) alloys. These two new materials 5083 and 5086 are work-hardening aluminum-magnesium-manganese alloys which have high strength in the annealed condition, possess good formability and excellent resistance to general and stress corrosion. Inert-gas arc welds in sheet and plate of these alloys exhibit ultimate tensile strengths of 42,500 psi for 5083 alloy and 38,700 psi for 5086 alloy with joint efficiencies varying from 80 to 100% depending on the original temper of the base plate. Data on inert-gas arc welds are presented for each alloy in various tempers and for gages ranging from $^1/_{16}$ to $^3/_4$ in. thick. Data presented include tensile properties and hardness surveys. Results of radiographic and metallo-

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Presented at Thirty-Fifth AWS National Fall Meeting held in Chicago, Nov. 1–5, 1954.

* To avoid confusion, the old designation and the new designation for aluminum alloys as established by the Aluminum Assn. are both used in this paper.

graphic examination are included. A survey of the effect of the heat of welding on the properties of the base plate is also presented. Spot-welded joints show efficiencies of 85 to 97% depending on joint design and original temper. Two-row spot weld joint strengths as high as 52,000 psi for 5086 and 55,000 psi for 5083 can be obtained. These strengths are comparable to the joint strength of similar designs in 2024-T3. Spot weld data on specimen width effect and weld shunt effect are presented and compared to similar data on 2024-T3. Spot weld strengths for gages ranging from 0.020 to 0.091 in. are given for 5086-H34 temper.

Introduction

The potentialities of aluminum as a construction material utilizing improved welding processes have become widely recognized in recent years. Consequently, a need for new alloys with still higher strength than existing alloys in the as-welded condition has become apparent. The aluminum-magnesium-manganese alloys offered attractive possibilities by virtue of their light weight, excellent corrosion characteristics and high strength in the annealed and cold-worked conditions. In contrast with 6061 (61S) and 2024 (24S) the excellent properties of the aluminum-magnesium alloys are realized by alloying and work-hardening rather than by heat treatment. For many years, the aluminum-magnesium alloy 5052 (52S) has been satisfactorily welded and excellent performance has been obtained. However, the tensile strength of weldments of 5052 (containing 2.5% Mg) is relatively low when compared with alloys of higher (4–5%) magnesium content.

The use of heat-treatable alloys for welded applications is frequently limited because of the difficulty or impossibility of subjecting the welded assembly to the heat-treating operation. Even though a heat-treated high strength base plate is used, the tensile strength of the structure in the as-welded condition is limited to the strengths of the weld metal and heat-affected zones in which the properties approach those of annealed parent metal. Since the aluminum-magnesium alloys possess high strengths in the annealed condition and are readily joined by inert-gas arc welding and resistance welding, the properties of as-welded joints in these alloys are markedly superior. Furthermore, the mechanical properties of the weld metal itself using

Table 1—Chemical Composition of 5083 and 5086

	5083			5086		
	Spec. limits		Analysis of test	Spec. limits		Analysis of test
Element	*Min*	*Max*	*material*	*Min*	*Max*	*material*
Silicon	...	0.40	0.13	...	0.40	0.11
Iron	...	0.40	0.25	...	0.50	0.21
Copper	...	0.10	Trace	...	0.10	Trace
Manganese	0.50	1.00	0.69	0.20	0.70	0.43
Magnesium	4.00	4.90	4.47	3.50	4.50	4.11
Chromium	...	0.25	0.05	...	0.25	0.14
Zinc	...	0.25	0.00	...	0.25	0.00
Titanium	...	0.15	0.08	...	...	0.00
Others						
Each	...	0.05	...	...	0.05	...
Total	...	0.15	...	...	0.15	...

Table 2—Tensile Properties of 5083 and 5086 Sheet and Plate Used in Welding Tests

	5083				5086			
	Tested in longitudinal direction				Tested in longitudinal direction			
Thickness, in.	*Temper*	*TS, psi*	*YS,* psi*	*Elongation, % in 2 in.*	*Temper*	*TS, psi*	*YS, psi*	*Elongation, % in 2 in.*
0.020	H32†	45,200	30,800	12.7	H34	46,500	37,000	9.0
0.030	H32†	46,600	34,500	12.0	H34	46,800	37,300	9.0
0.040	H32†	48,300	38,000	12.0	H34	46,800	36,700	9.7
0.064	H113†	45,800	30,700	15.2	H112†	47,000	40,800	9.0
0.064	H32†	49,500	39,200	12.5	H34	47,000	38,500	11.5
0.064	H34†	49,400	41,500	11.0	H32	45,000	34,000	11.5
0.091	H32†	46,900	32,400	16.7	H34	48,600	38,200	12.2
0.125	...	...	...	...	H112†	46,600	37,100	12.7
0.125	H113†	44,500	28,600	17.0	H34	45,500	34,300	12.0
0.125	H32†	48,000	37,800	14.0	...	...	...	...
0.250	0	42,500	19,800	23.4	0	38,700	17,500	30.0
0.250	...	...	...	...	H112	44,700	30,500	18.0
0.250	H113	53,300	39,900	16.5	...	...	...	...
0.250	...	...	...	...	H34	48,100	36,300	13.0
0.250	...	...	...	...	H36†	52,800	41,600	12.7
0.500	H113	45,100	32,100	18.5	H112	43,000	22,800	22.5
0.500	...	...	...	...	H34†	47,300	35,800	18.0
0.650	H32†	46,500	32,600	17.0	...	...	...	...
0.750	H113	45,900	34,000	17.7	H112	43,400	20,000	23.0
0.064	0†	47,000	23,600	21.0	0	40,000	19,600	24.0
0.064	H12*	56,900	53,200	6.9	H12†	46,400	40,300	9.0
0.064	H14†	62,800	59,300	5.2	H14†	50,000	46,000	6.2
0.064	H16†	65,000	60,600	4.5	H16†	54,000	49,700	7.0

* At 0.2% offset.

† Laboratory material. These tempers are not currently available commercially. Temper designations assigned to laboratory material are merely for the purposes of identification and do not necessarily represent typical properties for these tempers.

the parent aluminum-magnesium-manganese alloy for filler metal are similar to those of the annealed parent material.

A considerable amount of research has been conducted on the aluminum-magnesium-manganese type alloys in Europe, and several aluminum-magnesium and aluminum-magnesium-manganese alloys are being successfully used. In France, the alloys AG3, AG5 and AG7 containing 3, 5 and 7% magnesium, respectively, are extensively employed in marine, transportation and construction applications. In Germany, the aluminum-magnesium-manganese alloys, Peraluman 3, 5 and 7 containing 3, 5 and 7% magnesium with up to 0.8% manganese, are being used in similar applications. The British counterparts of these alloys are known as N5, N6 and NP5/6, and they are especially favored for shipbuilding purposes. Several examples of the application of these alloys may be found in the literature.[1–10]

Interest in the aluminum-magnesium alloys was revived in the United States when satisfactory techniques for welding these alloys were developed. On the basis of European experience, several compositions of aluminum-magnesium-manganese alloys were selected for extensive study by the Department of Metallurgical Research at Kaiser Aluminum & Chemical Corp. From this study, two alloys known as 5083 (LK183) and 5086 (K186) were selected to meet the needs of the expanding aluminum market.

Properties of Plate Materials 5083 and 5086

The chemical analyses of these alloys are given in Table 1. Alloy 5086 is a moderately high-strength alloy with good formability and excellent resistance to general and stress corrosion even in severe marine environments. It is produced in sheet, plate and extruded forms in a wide variety of tempers. The companion alloy 5083 has a higher strength but slightly lower formability than 5086 and also has excellent resistance to general and stress corrosion. It is presently produced only in plate or extruded forms in selected tempers. The tensile strengths of these alloys in the annealed condition are appreciably higher than that of 5052 and more than twice that of 6061.

These alloys consist essentially of a solid solution of magnesium in aluminum with small amounts of insoluble phases dispersed throughout the matrix. As the magnesium content is increased, the tensile strength also increases and the ductility is slightly reduced. The addition of manganese further improves the tensile strength but not without some sacrifice in ductility. The fabrication problems also become increasingly difficult as the magnesium and manganese contents are increased. Both alloys are inherently fine-grained.

Table 3—Comparative Mechanical and Physical Properties of Aluminum Alloys 5083, 5086, 5052, 6061 and 2024

		Alloy				Alloy	
Property	*Temper*	*5083*	*5086*	*5052*	*Temper*	*6061*	*2024*
Ultimate tensile strength, psi	0	44,000	38,000	28,000	0	18,000	27,000
	H112	44,000	39,000	...	T3	...	70,000
	H113	46,000	...	...	T4	35,000	68,000
	H34	50,000	47,000	38,000	T6	45,000	...
	H36	55,000	53,000	40,000	...	...	...
Yield tensile strength, psi	0	22,000	17,000	13,000	0	8,000	11,000
	H112	26,000	19,000	...	T3	...	50,000
	H113	33,000	...	...	T4	21,000	47,000
	H34	41,000	37,000	21,000	T6	40,000	...
	H36	44,000	41,000	35,000	...	...	...
Elongation, % in 2 in.	0	21	22	25	0	25	20
	H112	19	14	...	T3	...	18
	H113	16	...	...	T4	22	20
	H34	11	13	10	T6	12	...
	H36	9	12	8	...	...	...
Ultimate shearing strength, psi	0	25,000	23,000	18,000	0	12,000	18,000
	H34	...	27,000	21,000	T3	...	41,000
	H36	...	...	23,000	T4	24,000	41,000
					T6	30,000	...
Ultimate bearing strength, psi	0	88,000	79,000	61,000	T3	...	129,000
	H34	...	97,000	78,000	T4	73,000	...
	H36	...	...	82,000	T6	94,000	...
Modulus of elasticity in tension × 10^6, psi		10.3	10.3	10.2		10.0	10.6
Endurance limit, psi for 500 × 10^6 cycles	0	...	...	17,000	0	9,000	13,000
	H34	...	16,000	18,000	T3	...	20,000
	H36	...	...	19,000	T4	14,000	20,000
	H112	...	22,000	...	T6	14,000	...
Electrical conductivity at 20° C (% IACS equal vol.)	0	28.9	31.32	35	0	45	50
	H34	28.9	31.32	35	T3	...	30
					T4, T6	40	...
Electrical resistivity at 20° C (microhm-cm)	0	5.79	5.52	4.9	0	3.8	3.4
	H34	...	5.49	4.9	T3	...	5.7
					T4, T6	4.3	...
Thermal conductivity at 25° C, cal/cm²/cm/° C/sec	0	0.275	0.30	0.33	0	0.41	0.45
					T3	...	0.29
					T4, T6	0.37	...

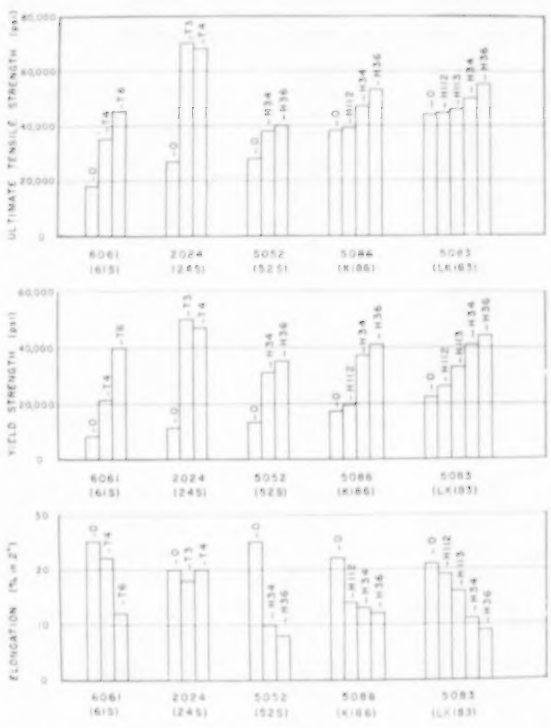


Fig. 1 Bar graph illustrating comparative mechanical properties of five aluminum alloys including 5083 and 5086 in a range of tempers

The tensile properties of the sheet and plate used in the welding tests are listed in Table 2. For comparative purposes, the mechanical and physical characteristics of 5083, 5086, 6061, 5052 and 2024 are presented in Table 3. The comparative tensile properties of these alloys are illustrated graphically in Fig. 1. It should be noted particularly that the lower thermal conductivity of 5083 and 5086 is an advantage in welding. The lower specific gravity also tends to give them a more favorable strength-weight ratio than is indicated in Table 3.

Inert-Gas Metal-Arc and Tungsten-Arc Welds

All arc welds were made on plates 6 × 16 in., using the welding procedures detailed in Table 4. All plates were thoroughly degreased prior to welding and held firmly in a jig using a water-cooled, copper backing bar. The welding was done in the flat position with no preheat applied to the base plate. Welds in $^1/_{16}$- and $^1/_8$-in. sheet were made with the inert-gas tungsten-arc process whereas all other welds in the heavier gages were made with the inert-gas metal-arc welding process.

Arc Weld Test Results and Discussion

Welds from each group were examined radiographically to assure that x-ray quality welds were obtained. The welded specimens were then sectioned for further testing. Samples were cut from representative welded joints for macro-examination, and typical sections are shown in Figs. 2, 3 and 4 which illustrate the sound weld metal obtained. These sections also show the major modes of fracture of the tensile specimens. Figure 2 is a section of an inert-gas metal-arc weld made in $^1/_4$-in. thick 5083-H113 material which fractured in the heat-affected zone of the parent metal. Figure 3 is a similar specimen with the beads machined off prior to testing. The shear angle type of fracture indicates sound weld metal. Figure 4 is a macro-section of a weld in $^3/_4$-in. thick 5086-H112 plate showing sound weld metal and fracture along the fusion line. Most of the samples tested in this program fractured by one of these three methods or by a combination of the three types. Any weld unsoundness would result in a jagged irregular fracture.

A chemical analysis was made of the weld metal of representative welds and the results are shown in Table 5 together with the composition of the filler wires used. The composition of the weld metal is affected by the dilution of the filler wire with the base plate and by a slight loss of magnesium in the inert-gas metal-arc process. The use of 5056 or 5083 wire in the inert-gas metal-arc process results in considerably more spatter and fume than is encountered with 4043 (43S) welding wire. This is more pronounced when helium gas is used. In spite of this spatter, the weld metal composition remains within the specified limits of the alloy. In applications where the beads are to be removed and where heavier gages are used, it would be desirable to have a higher alloy content in the weld metal to match the mechanical properties of the heat-affected zone.

Table 4 Welding Procedures Used in Tungsten Arc and Inert-Gas Metal-Arc Welding of 5083 and 5086 Test Panels

	Thickness, in.						
	$^1/_{16}$	$^1/_8$	$^1/_4$	$^1/_2$	$^3/_4$	$^3/_4$	$^3/_4$*
Process	Tungsten Arc	Tungsten Arc	IGMA†	IGMA	IGMA	IGMA	IGMA
Filler alloy	5056	5056	5083	5083	5083	5083	5056
Filler diam, in.	$^1/_8$	$^1/_8$	$^1/_{16}$	$^1/_{16}$	$^3/_{32}$	$^3/_{32}$	$^1/_{16}$
Joint type	Sq. butt	Sq. butt	Sq. butt	Double V, 60 deg	Double V, 60 deg	Double V, 60 deg	Sq. butt
No. of passes	1	1	2	2	3	4	2
Argon gas flow, cfh	20	25	60	60	60	60	80 (A + He)
Current, amp	170	240	250	290	325	325	350
Arc voltage			28	29	29–30	29–30	33
Rate of welding, ipm	13–5	7	16	4–6	3–5	3–4	6
Diameter of tungsten, in.	$^1/_8$	$^3/_{16}$					

* The procedure indicated in this column was used for samples shown in Table 8.
† Inert-gas metal-arc, consumable electrode.

Table 5—Chemical Analysis of Weld Metal Samples from Typical Welds and of Filler Wire Used in Making the Joints

Alloy and gage of base plate	*Filler wire alloy*	*Mg*	*Mn*	*Cr*	*Si*	*Fe*	*Cu*
		Analysis of filler wire					
	5056	5.17	0.12	0.12	0.10	0.22	0.02
	5083	5.00	0.74	0.12	0.10	0.20	0.02
		Analysis of weld metal					
		Mg	*Mn*	*Cr*	*Si*	*Fe*	*Cu*
Inert-gas metal-arc, consumable electrode							
5083							
1/4 in.	5083	4.61	0.70	0.16	0.11	0.23	0.04
1/2 in.	5083	4.48	0.70	0.12	0.11	0.22	0.02
5086							
1/4 in.	5083	4.34	0.57	0.17	0.12	0.23	0.01
1/2 in.	5083	4.49	0.64	0.14	0.12	0.20	0.02
Tungsten arc							
5083, 1/2 in.	5056	4.68	0.46	0.08	0.13	0.29	0.02
5086, 1/2 in.	5056	4.51	0.31	0.11	0.11	0.22	0.02

Standard transverse tensile specimens were prepared from the welded plates. These were machined and tested in accordance with the specification in the WELDING HANDBOOK, Third Edition, 1950, Fig. 12, page 1453. Ultimate tensile strength, yield strength and elongation were recorded using a 2-in. extensometer and gage length. These data are shown in Tables 6, 7 and 8. Each of these figures shown is an average of six tests. While the significance of the yield strength and elongation measurements across this heterogeneous zone is questionable, they were recorded primarily for comparison with the data obtained from the substandard tensile bars discussed later on. It may be possible to use these figures in a comparative way in relation to other alloys welded under similar conditions. The measured yield strength across a weld is a joint function of gage length used and cross section of the specimen. This makes it even more difficult to compare yield strengths of welded specimens.

The properties of the weld test samples do not appear to be affected either by original temper or gage since no trend can be observed from these data. The high strengths and joint efficiencies recorded here can be produced consistently by the inert-gas metal-arc welding process. The data shown in Table 8 indicate that the yield strength of the base plate can be materially improved by stretching. However, the properties of as-welded joints made in these plates are independent of the original condition of the base plate. These welds in 5083-H113 3/4-in. plate were made in two passes with no root opening or back-chipping between passes. A high degree of weld soundness was produced

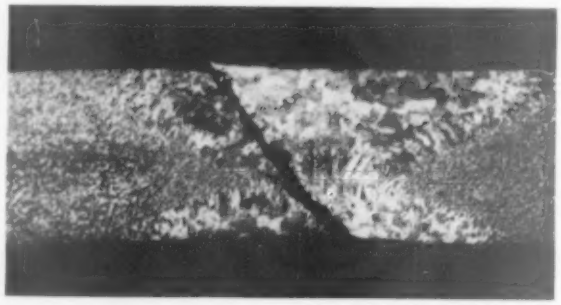


Fig. 3 Macro section of a tensile fractured inert-gas metal-arc test sample made in 5083-H113 alloy 1/4 in. thick. Tensile fracture with beads removed occurred in the weld metal

Fig. 2 Macro section of a tensile fractured inert-gas metal-arc test sample made in 5083 alloy 1/4 in. thick. Tensile fracture with beads in place occurred in heat-affected zone

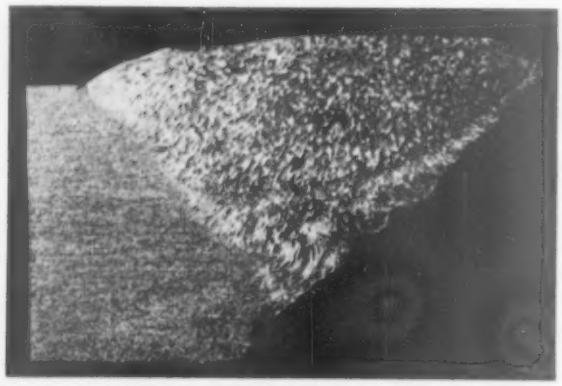


Fig. 4 Macro section of weld in 5086-H112 3/4-in. plate. Tensile fracture with beads in place occurred along the fusion line between weld metal and base plate

Table 6—Mechanical Properties of Tungsten Arc Welded Joints in Aluminum Alloys 5086 and 5083

Alloy, temper and gage	Tensile strength, psi	Yield strength,* psi	Elongation % in 2 in.	Joint efficiency, %	Location of fracture
		Tested with beads in place			
5086, H112, 1/16 in.	39,800	23,700	6.8	84.5	Parent plate
5086, H34, 1/16 in.	40,200	21,500	8.3	85.5	Parent plate
5086, H112, 1/8 in.	40,000	22,700	11.5	85.9	Parent plate
5086, H34, 1/8 in.	40,700	22,700	10.4	89.5	Parent plate
		Tested with beads machined off			
5086, H112, 1/16 in.	41,300	25,500	6.7	88	Parent plate and weld metal
5086, H34, 1/16 in.	39,700	19,000	8.5	84.5	Weld metal
5086, H112, 1/8 in.	37,400	20,200	8.6	80	Weld metal
5086, H34, 1/8 in.	37,600	19,900	9.3	82.6	Weld metal
		Tested with beads in place			
5083, H113, 1/16 in.	42,600	26,300	8.8	93	Parent plate
5083, H32, 1/16 in.	44,100	26,700	7.8	89	Parent plate and fusion line
5083, H113, 1/8 in.	40,900	23,100	9.8	92	Parent plate and fusion line
5083, H32, 1/8 in.	42,100	20,600	9.4	87.9	Parent plate and fusion line
		Tested with beads machined off			
5083, H32, 1/16 in.	40,600	24,600	6.2	82.1	Weld metal
5083, H113, 1/8 in.	41,600	21,900	12.3	93.5	Fusion line
5083, H32, 1/8 in.	41,600	20,400	10.5	86.7	Fusion line weld metal

* At 0.2% offset.

and samples fractured in the heat-affected zone with ultimate tensile strengths averaging 42,000 psi.

A comparison of typical mechanical properties of welded joints in various aluminum alloys is shown in Table 9. This clearly illustrates the superior strength of as-welded joints in 5083 and 5086 as compared to the strength of joints in 6061 and 5052. The strength of as-welded joints in 5083 is more than 40% greater than those in 6061. However, where postweld heat treatment is possible, 6061 and possibly 2024 offer some advantages.

Typical tensile specimens are illustrated in Figs. 5 and 6. Figure 5 shows the types of fracture obtained when beads are left on and when they are removed. Figure 6 shows a typical weld fracture in 3/4-in. plate welded in 2 passes. This figure also shows the appearance of the sample before machining for test.

In order to explore more fully the nature of the heat-affected zone of welds in 5083 and 5086, a series of substandard tensile bars 1 3/4 in. long and 1/8 in. diam (Welding Handbook, page 1446, Fig. 3, c-5) were taken at regular intervals on both sides of the weld. The longitudinal axis of these samples was parallel to the weld bead. The data so obtained are presented

Table 7—Mechanical Properties of Inert-Gas Metal-Arc Welded Joints in Aluminum Alloys 5086 and 5083

Alloy, temper and gage	Tensile strength, psi	Yield strength,* psi	Elongation % in 2 in.	Joint efficiency, %	Location of fracture
		Tested with beads in place			
5086, 0, 1/4 in.	39,300	17,900	15.4	100	Parent plate, fusion line
5086, H112, 1/4 in.	39,200	19,400	14.0	87.6	Parent plate, fusion line
5086, H34, 1/4 in.	37,600	20,700	8.3	78	Parent plate, fusion line, weld metal
5086, H36, 1/4 in.	39,600	21,100	9.3	75	Parent plate, fusion line
5086, H112, 1/2 in.	39,200	21,000	11.4	91.2	Fusion line
5086, H34, 1/2 in.	39,000	20,500	12.0	82.5	Fusion line
5086, H112, 3/4 in.	41,000	20,500	16.7	94.5	Fusion line, parent plate
		Tested with beads machined off			
5086, 0, 1/4 in.	35,500	17,100	12.5	91.6	Fusion line
5086, H112, 1/4 in.	36,600	17,000	14.3	81.9	Fusion line and weld metal
5086, H34, 1/4 in.	36,900	18,000	12.9	76.7	Fusion line and weld metal
5086, H112, 1/2 in.	41,000	20,300	16.5	95.5	Fusion line
5086, H112, 3/4 in.	39,400	19,700	16.8	90.7	Fusion line and weld metal
		Tested with beads in place			
5083, 0, 1/4 in.	43,100	20,400	16.2	100	Fusion line, parent plate
5083, H113, 1/4 in.	45,300	26,100	11.8	85	Parent plate
5083, H113, 1/2 in.	40,600	21,800	12.5	90	Fusion line
5083, H32, 0.650 in.	41,000	21,700	12.3	88.1	Parent plate, fusion line
5083, H113, 3/4 in.	42,800	21,100	15.0	93	Fusion line
		Tested with beads machined off			
5083, 0, 1/4 in.	40,600	20,100	15.3	95.5	
5083, H113, 1/4 in.	41,900	22,400	14.0	78.7	Weld metal
5083, H113, 1/2 in.	39,200	19,700	13.6	87	Weld metal
5083, H32, 0.650 in.	40,900	19,700	16.4	88	Fusion line, weld metal
5083, H113, 3/4 in.	41,700	20,300	17.0	91	Weld metal

* At 0.2% offset.

Table 8—Mechanical Properties of $^3/_4$-In. 5083-H113 Plate and of Welded Specimens Made in the Plate After Various Amounts of Stretching (Welds Made with 5056 Wire $^1/_{16}$ In. Diameter)

Stretch, %	Tensile strength, psi		Yield strength, psi*		Elongation % in 2 in.	
	Weld	Base plate	Weld	Base plate	Weld	Base plate
0.89	42,700	45,400	20,300	25,700	13.8	22.5
1.67	41,400	45,200	20,700	29,300	12.8	21.2
2.8	41,800	45,500	20,100	30,900	12.3	20.2
3.6	42,200	45,600	21,400	33,300	13.0	19.2
4.8	42,800	46,700	21,400	36,000	14.0	19.0
5.9	41,400	47,300	20,800	38,600	12.8	17.0
Avg for all welds	42,000	...	20,600	...	13.0	

* At 0.2% offset.

Table 9—Comparison of Typical Mechanical Properties of Welds in Aluminum Alloys 5083, 5086, 6061, 5052 and 2024

Alloy and temper	Filler wire	Condition*	Tensile strength, psi	Yield strength,† psi	Elongation % in 2 in.
5083, H113	5083 or 5056	A. W.	42,500	22,000	12.0
5086, H112	5083 or 5056	A. W.	39,800	21,000	12.5
5052, ¼H	4043, 5052, 5056	A. W.	28,000	14,000	15.0
6061, T6	4043	A. W.	30,000	21,000	8.5
6061, T6	5083	A. W.	32,500	21,000	9.0
2024, T3	2024	A. W.	40,000	20,000	4.0
6061, T6	4043	H. T.	44,000	40,000	5.0
2024, T3	2014, 2017, 2024	H. T.	54,000	45,000	4.0

* A. W., as welded. H. T., solution heat treated and aged after welding.
† At 0.2% offset.

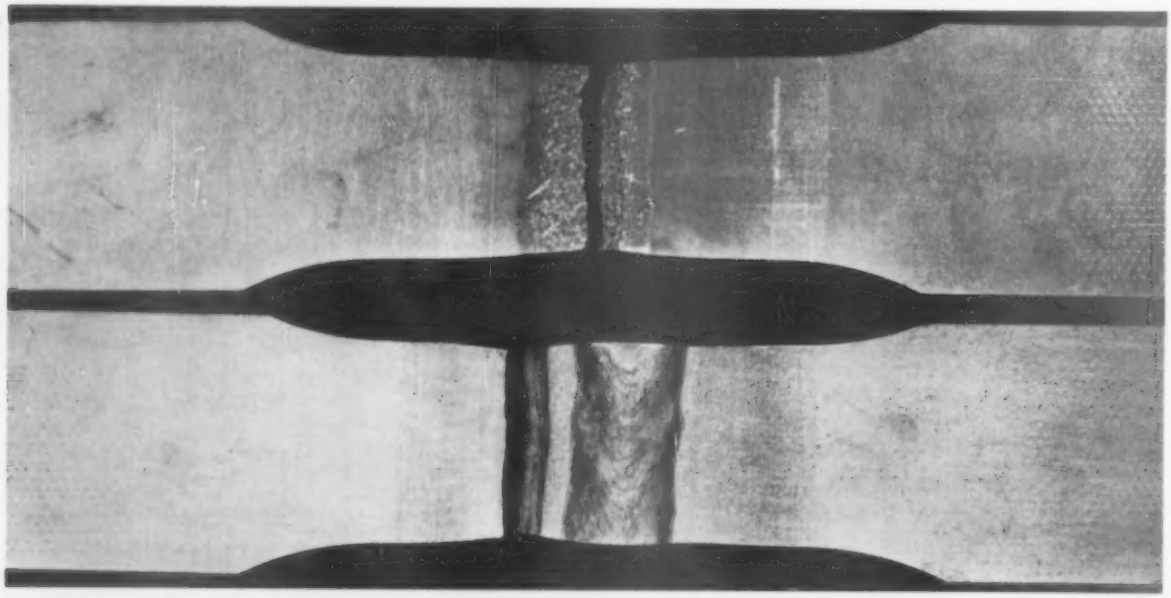


Fig. 5 Fractured tensile specimens of welds in 5083-H113 $^1/_4$-in. plate showing fracture in the annealed zone when beads are left on and fracture in the weld metal when beads are removed before testing

in Table 10. Each figure in this table is the average of five tests. The spread in the data on individual tests within a group was remarkably small, indicating good correlation. The first centerline value in each case gives the properties of the weld metal itself. It is particularly interesting to note the excellent elongation obtained on these samples. In no case did the elongation decrease to a value near that obtained on most standard transverse tensile specimens. Thus each zone, weld metal included, is far more ductile than is suggested by the elongation in 2 in., of standard trans-

Fig. 6 Typical tensile specimens of welds made in 5083 H113 $^3/_4$-in. plate using 2 passes square butt joint. Bottom shows weld before machining and top shows fractured samples. Note good penetration and fracture in annealed zone

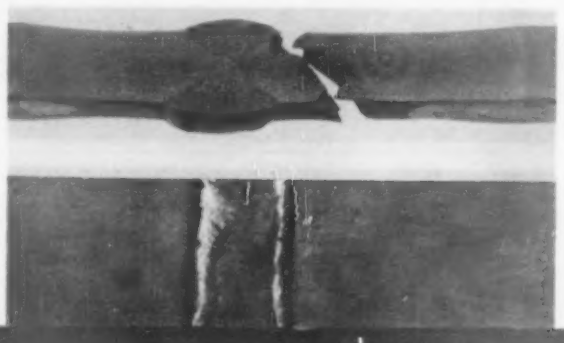


Table 10—Table Showing Variation in Mechanical Properties of Metal in the Area of Inert-Gas Metal-Arc Welds in 5083 and 5086 Using 5083 Filler Wire

Distance from ℄ of weld, in.	5083-H113			5083-H32			5086-H112			5086-H34		
	TS, psi	YS,* psi	Elongation % in 1 in.	TS, psi	YS, psi	Elongation % in 1 in.	TS, psi	YS, psi	Elongation % in 1 in.	TS, psi	YS, psi	Elongation % in 1 in.
℄	39,170	20,250	24.0	34,375	18,900	12.5	35,275	17,900	16.5	35,750	17,933	20.7
0.172	41,270L†	19,400L	26.0L	33,950	19,450	9.0	32,833	17,367	12.7	40,067	19,233	15.3
	39,360R†	19,720R	28.5R	37,875	24,350	10.5	33,925	17,675	12.5	38,825	18,775	18.0
0.344	42,820L	20,240L	28.4L	39,700	19,350	13.0	38,450	18,525	22.5	39,450	18,325	15.0
	43,620R	19,300R	28.4R	38,400	19,350	11.5	37,933	17,367	22.7	36,400	18,325	15.0
0.516	46,980L	29,540L	20.0L	42,550	24,375	15.0	38,434	16,934	23.3	46,075	27,100	23.5
	43,700R	22,520R	26.0R	40,875	27,500	10.0	39,125	17,500	23.0	45,250	25,525	23.0
0.688	48,140L	28,600L	21.2L	43,250	27,825	13.0	41,875	23,400	25.5	43,700	22,050	27.0
	47,320R	26,820R	23.2R	41,375	27,775	11.0	44,375	21,950	24.0	43,950	22,350	25.0
0.859	47,180L	30,580L	18.8L	44,300	31,075	10.0	43,225	30,100	22.0	49,250	34,025	22.5
	46,620R	27,620R	20.4R	44,100	31,400	10.0	43,750	27,825	18.5	49,475	35,050	20.0
1.032	49,620L	32,550L	18.4L	45,275	32,567	12.5	41,700	27,300	29.0	48,725	34,275	23.5
	49,060R	32,180R	19.6R	44,625	31,400	12.0	44,775	30,050	22.0	49,275	33,225	22.5
1.203	47,540L	30,880L	18.4L	45,600	34,033	8.7	43,500	30,100	18.5	50,225	35,875	19.5
	47,820R	30,460R	19.2R	45,925	35,075	13.0	43,675	28,675	21.5	50,225	35,250	18.0
1.375	49,300L	34,060L	18.0L	47,050	35,350	13.0	43,875	27,225	26.5	50,100	36,050	20.5
	49,440R	33,160R	18.0R	46,500	34,450	13.5	43,825	28,367	21.0	50,350	36,467	18.7
1.547	47,400L	30,940L	16.0L	46,950	35,375	9.5	43,750	29,075	13.0	50,875	36,450	20.5
	47,860R	30,980R	17.6R	46,625	35,225	10.5	43,825	28,900	26.5	50,450	36,050	22.0
1.716	49,440L	32,280L	17.6L	48,525	36,325	16.5	43,450	27,050	23.5	49,767	36,233	18.0
	49,160R	33,520R	18.8R									
1.891	46,870L	30,770L	14.5L									
	47,620R	31,400R	18.0R									
2.060	48,100L	34,100L	9.0L									
	49,750R	33,950R	18.0R									

* At 0.2% offset.
† L, sample taken to left of weld bead. R, sample taken to right of weld bead.

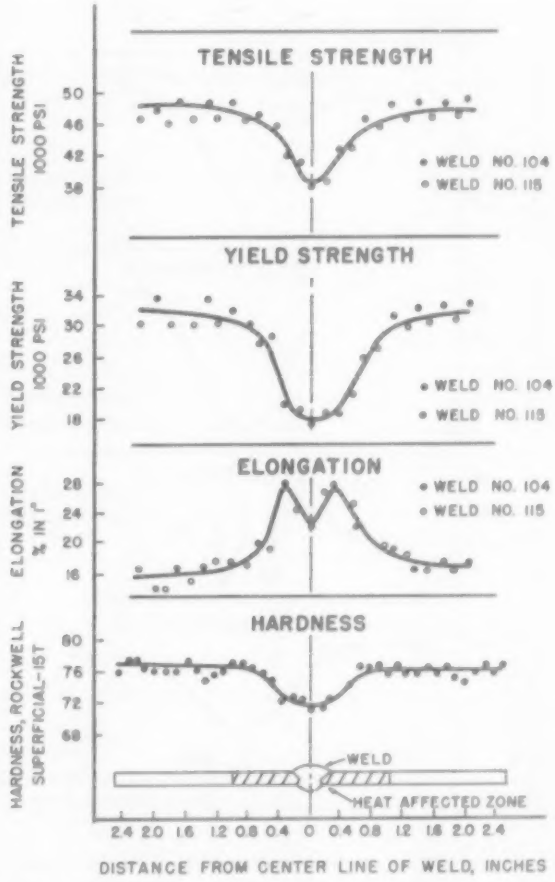


Fig. 7 Variation of mechanical properties in the weld area as measured by substandard tensile bars and Rockwell hardness. Samples taken from 0.250-in. 5083-H113 welded with 5083 filler wire

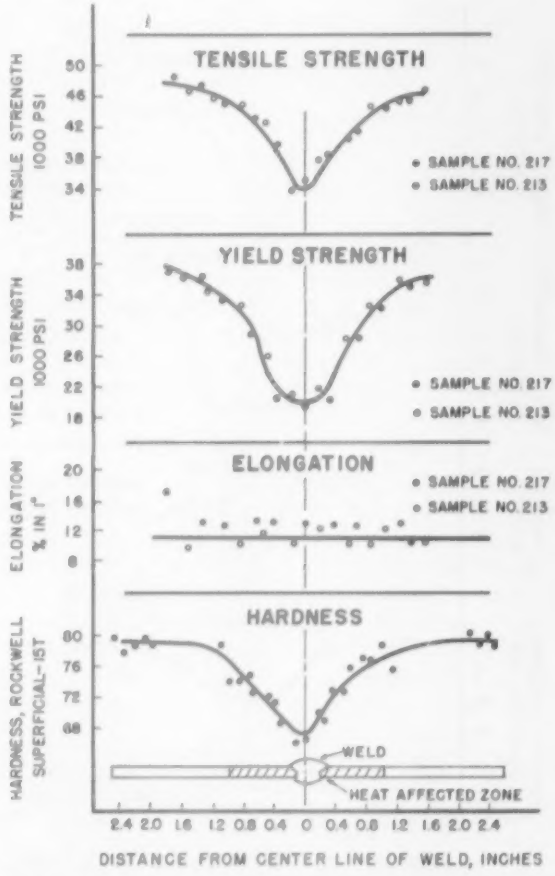


Fig. 8 Variation of mechanical properties in the weld area as measured by substandard tensile bars and Rockwell hardness. Samples taken from 0.250-in. 5083-H32 welded with 5083 filler wire

verse tensile specimen.

The data of Table 10 are plotted in Figs. 7, 8, 9 and 10 showing, on the same graph, the variation of mechanical properties (tensile strength, yield strength, elongation and hardness) across the weld and heat-affected zone. Because of the method used in cutting samples, every other point on the curve is cut from the same plate so that two welded samples were necessary for each curve. The curves shown, therefore, represent the mean value for the properties of both welded samples. The sharp change in metallurgical structure from cast metal through annealed base plate to full base plate temper constitutes a metallurgical notch. This notch is not so severe for welds in 5083-H113 or 5086-H112 as it is for welds in alloys such as 6061-T6, although it extends the same distance out from the weld. The hardness curves shown give a good indication of the extent and magnitude of this heat-affected zone for each of the alloys.

To further illustrate how the yielding and stretching are confined to the most completely annealed areas, a series of stress-strain curves obtained from the substandard tensile bars is shown in Fig. 11. It is apparent from these curves why the recorded elongation on 2 in.

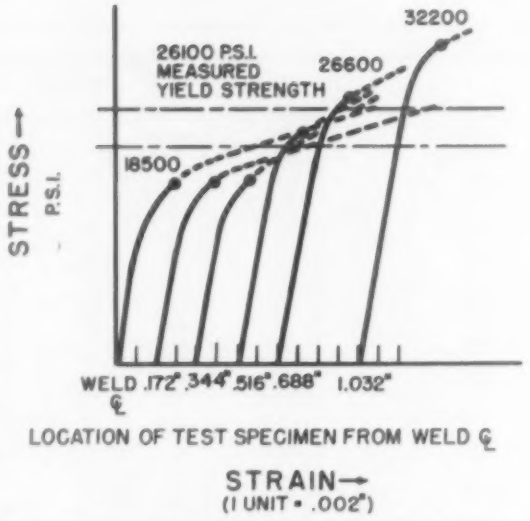


Fig. 11 Stress-strain curves of substandard tensile bars taken at various locations in the weld heat-affected zone. The horizontal lines indicate the yield strength with beads in place (26,000 psi) and with beads removed (22,000 psi) measured on standard transverse tensile specimens. The dot on each curve represents the yield strength of the substandard specimens

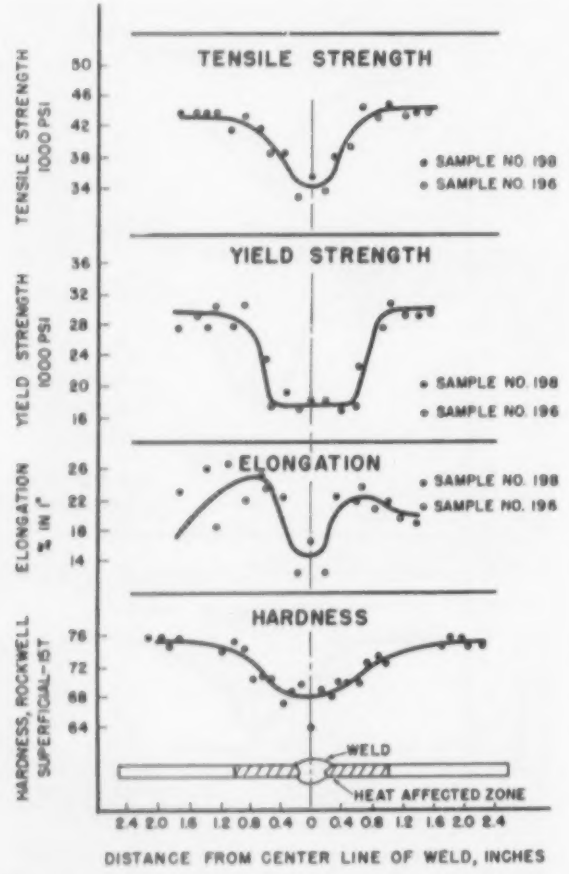


Fig. 9 Variation of mechanical properties in the weld area as measured by substandard tensile bars and Rockwell hardness. Samples taken from 0.250-in. 5086-H112 welded with 5083 filler wire

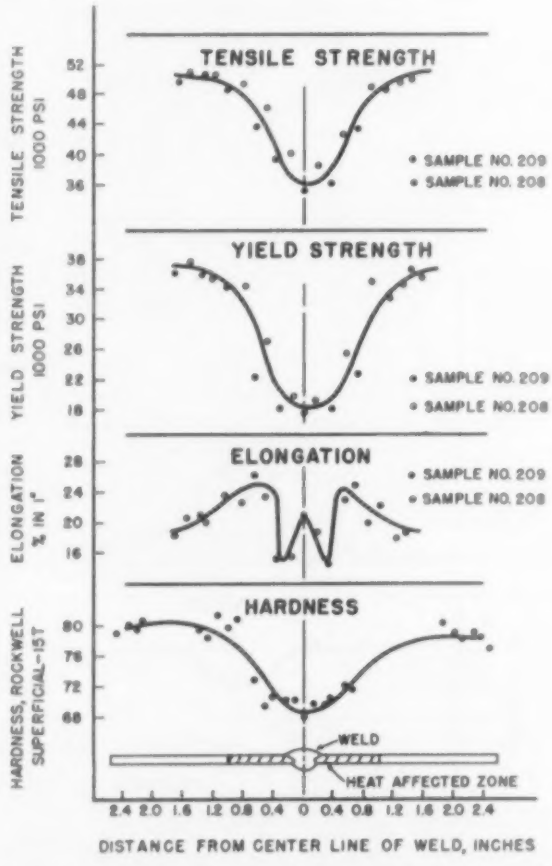


Fig. 10 Variation of mechanical properties in the weld area as measured by substandard tensile bars and Rockwell hardness. Samples taken from 0.250-in. 5086-H34 welded with 5083 filler wire

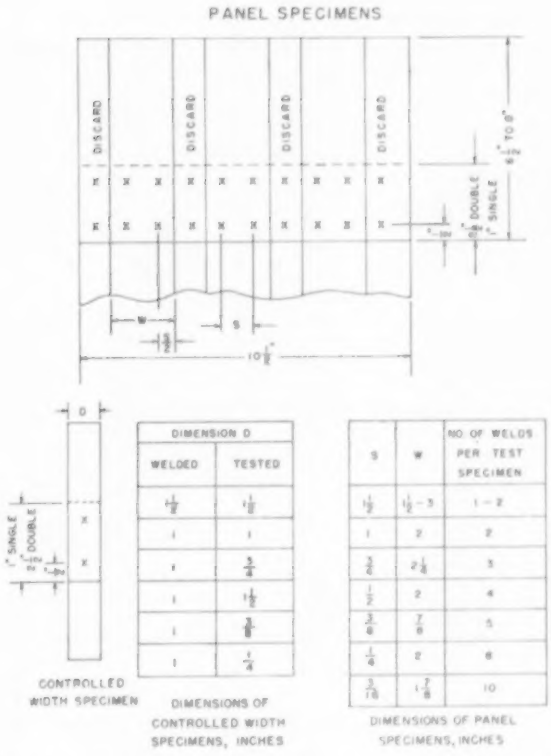


Fig. 12 Sketch and table showing dimensions and methods of selection of spot-welded test specimens

in a standard test specimen gives a false impression. It is also obvious that the yield strength of the annealed material should be used in designing welded structures, since the yield strength recorded in a transverse tensile test is higher than the yield strength of the annealed zone.

When welded plates are subjected to stresses perpendicular to the weld bead, practically all the yielding and strain occurs within $\pm 1/2$ in. from the weld metal. This distance will vary somewhat with the gage of the plate and details of the welding procedure. The metallurgical notch in the weld heat-affected zone is more severe in material that has a high strength relative to its strength in the annealed condition. In designs where this notch is critical, it is advantageous to use 5083-H113 or 5086-H112.

Spot Welds in Aluminum Alloys 5083 and 5086

The principal physical difference between the two aluminum alloys 5083 and 5086 and other aluminum alloys is their relatively high strength in the fully annealed condition. To properly evaluate this factor in connection with the spot welding process it was desirable to produce joints which failed in tension in the parent metal rather than by shearing of the welds.

Four specimen types were used in this investigation:

1. Single-row panels with various spacings.
2. Single-weld specimens of various controlled widths.
3. Double-row panels with various spacings.
4. Tandem-spot specimens of various controlled widths.

The single-row panel specimen represents a typical production joint. Strength of a given spot weld is influenced by its proximity to previously completed welds since welding current is lost by shunting through adjacent welds. This loss of strength is commonly referred to as shunt loss.

The single-spot specimen is the most commonly used laboratory and shop set-up specimen. It is typical of the first weld in a production panel since it has no shunt loss. An evaluation of shunt loss can be made by comparing single-spot controlled width specimens with representative panel specimens. The strength of a single-spot specimen varies with the specimen width. As the test load is applied, the two pieces comprising the specimen attempt to align on a common axis. This induces bending in the region of the weld, and it is no longer subjected to simple shear but a combination of shear and tension. With very wide specimens, the amount of bending decreases and higher weld strength results. The same bending effect is present in panel specimens.

The double-row panel specimen is of interest because of the high strength that can be developed. Shunting between rows can be minimized by using a relatively wide distance. The work of Crawford and Pease[11] was used as a guide in selecting the distance between rows.

The tandem-spot specimen of controlled width is comparable to the two-row panel specimen except that shunting is minimized. It would be physically possible to compensate for shunting in spot-welded joints by increasing the welding current. At present we do not have enough experimental data to do this properly, but the single- and tandem-spot controlled-width specimens do give an indication of the joint strength that might be realized by shunt compensation.

Procedures

Dimensions of the various specimens are shown in Fig. 12. In the lower left side of Fig. 12 single- and double-spot controlled-width test samples are shown with a table of dimensions. The upper sketch and table in the lower right-hand corner show the method of selection and the size of panel-welded specimens. The number of welds for each S and W combination is shown for single-row panels. For double-row panels the number of welds is twice that shown for single-row panels. All welding was done on a Taylor-Winfield HWRD-36 RA condenser discharge spot-welding machine. Machine operation was recorded by means of a Brush two-element oscillograph using a portion of the upper electrode as the current shunt. Control of the oscillograph was interconnected with the welding machine circuit and an auxiliary timer so that an oscillogram of proper length could be obtained on each weld without attention from the operator.

Accurate and uniform spacing of welds in the panel specimens was insured by use of a non-magnetic indexing table attached to the lower arm of the welding machine. Specimens of controlled width were welded in phenolic jigs which fixed the lap, alignment and weld location.

Prior to welding, the specimens were degreased by a 10-min immersion in Oakite 63 at 170° F followed by a 5-min rinse in cold running water. This was followed by a 6-min immersion in a chromic acid type etching solution at room temperature and a second 5-min rinse in cold running water. The specimens were dried in a warm air blast. Immediately prior to welding, the parts were rotary wire brushed. Inclusion of the etching treatment was found to speed up the wire brushing. In this investigation no attempt was made to develop optimum chemical cleaning procedures.

Machine settings used for the various tempers and alloys are given in Table 11. Each setting was developed by first selecting a standard electrode force which was used with a given thickness of metal regardless of alloy or temper. The welding current was increased to give the highest shear value that could be obtained without cracking or expulsion. Macro-examination of sectioned welds was used as a check of proper penetration and absence of gross defects.

Individual samples were sawed from the welded panels as shown in Fig. 12. All specimens which would obviously fail by shearing of the welds received no further treatment prior to testing. Edges of specimens which might fail in tension were power-belt sanded parallel to the long axis and measured for thickness and width. Final results of all tests were converted to pounds per square inch of specimen cross section.

As the plotted curves indicate, a hyperbolic scale was used for the weld spacing. The scale was so selected that the reciprocal of weld spacing (welds per inch) resulted in a linear scale. In studying the curves it is important that the concept of welds per inch be kept in mind.

Table 11—Spot-Weld Machine Settings Used in Preparing Test Specimens in 5083 and 5086

	Temper				
	H12	*H14*	*H16*	*H32*	*H34*
5083, 0.064 in. thickness					
Welding force, lb	1400	1400	1400	1400	1400
Secondary force, lb	3600	3600	3600	3600	3600
Time delay, millisec	45	50	45	45	45
Capacitance, μf	1440	1440	1440	1440	1440
Charging voltage	1800	1900	1900	1750	1850
Transformer turns ratio	450:1	450:1	450:1	450:1	450:1
5086, 0.064 in. thickness					
Welding force, lb	1400	1400	1400	1400	1400
Secondary force, lb	3600	3600	3600	3600	3600
Time delay, millisec	50	50	50	50	50
Capacitance, μf	1440	1440	1440	1440	1440
Charging voltage	1850	1900	1950	1950	1850
Transformer turns ratio	450:1	450:1	450:1	450:1	450:1

	Thickness, in.				
	0.020	*0.032*	*0.040*	*0.091*	*0.064*
	5086-H34				2024 T3
Welding force, lb	450	675	825	2000	1400
Secondary force, lb	..	..	..	5400	3600
Time delay, millisec	..	..	..	35	40
Capacitance, μf	240	480	600	2640	1440
Charging voltage	2150	1900	1950	1950	1850
Transformer turns ratio	300:1	300:1	300:1	450:1	450:1

Electrodes: $^{3}/_{8}$-in. diam, 3 in. spherical radius except 0.091; $^{5}/_{8}$-in. diam, 4 in. spherical radius 0.091 only.

Effect of Temper on Spot-Weld Strengths of Alloys 5083 and 5086

The first test series included 0.064-in. sheet from alloys 5083 and 5086 each in five tempers and from alloy 2024-T3 for comparison. Grain direction of all specimens in this series was perpendicular to the long axis of the specimen. The results are plotted in Figs. 13 to 23. The lowest curve marked *S* in each figure gives the tensile results of specimens cut from single-row

Figs. 13–23 Joint strength vs. weld spacing for four types of spot-weld specimens: Single-spot, single-row panel joint, double-spot, and double-row panel joint. Width of the single- and double-spot specimens is plotted on the same abscissa as weld spacing for the panel joint specimens. Welds were made in a range of tempers in alloys 5083 and 5086

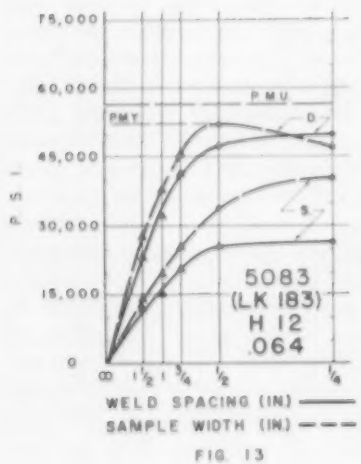


FIG. 13

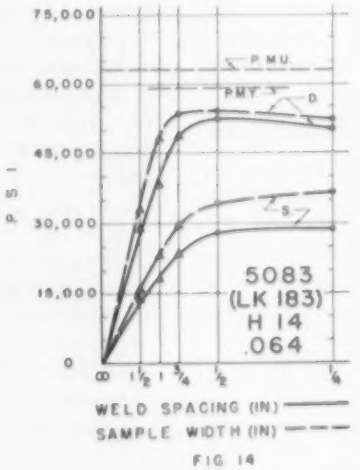


FIG. 14

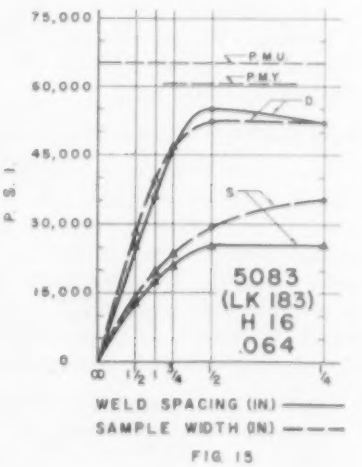


FIG. 15

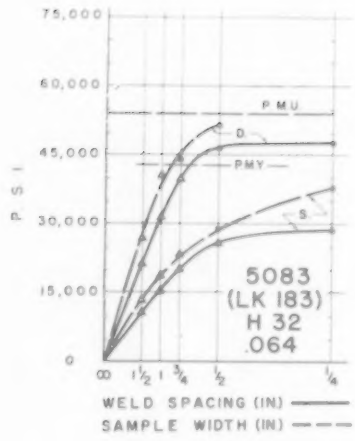


FIG. 16

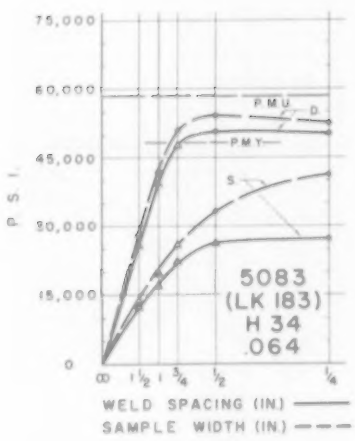


FIG. 17

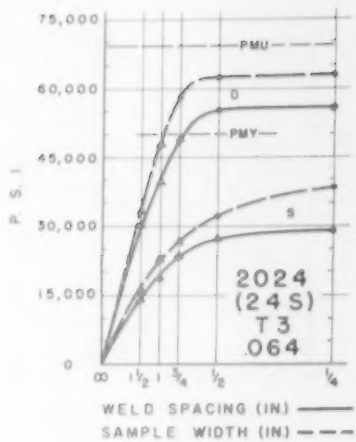


FIG. 18

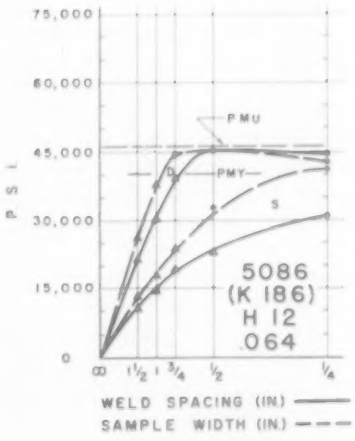


FIG. 19

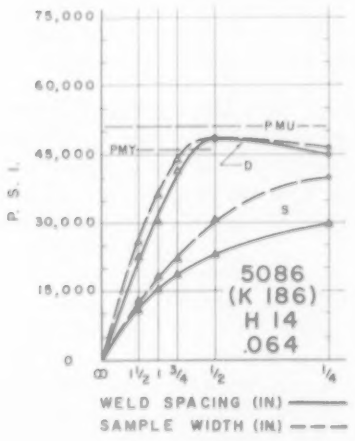


FIG. 20

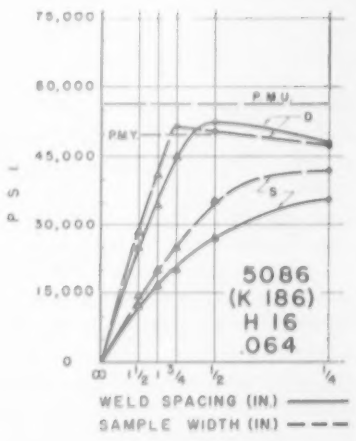


FIG. 21

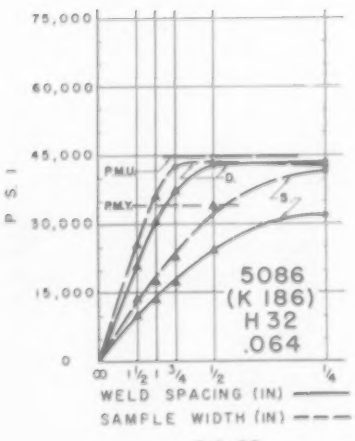


FIG. 22

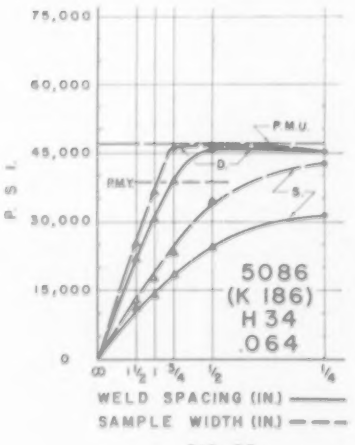


FIG. 23

KEY TO SYMBOLS

A SHEAR FAILURE

* TENSION FAILURE

D. DOUBLE ROW

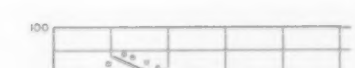
S. SINGLE ROW

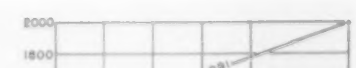
P.M.U. PARENT METAL-ULTIMATE

P.M.Y. PARENT METAL-YIELD

——— SPECIMENS FROM PANELS

– – – SPECIMENS OF CONTROLLED WIDTH





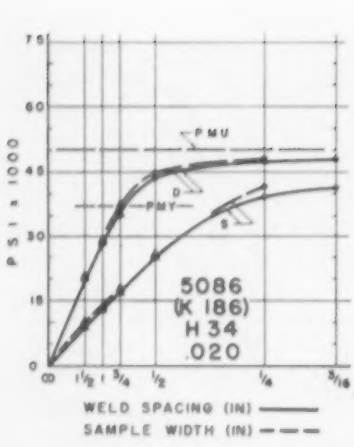


FIG. 24

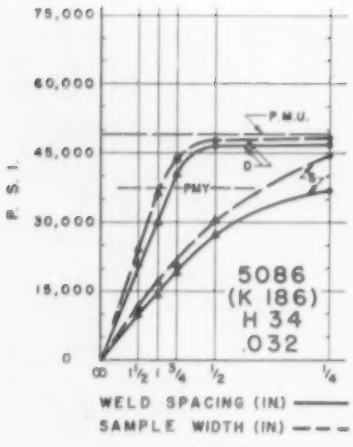


FIG. 25

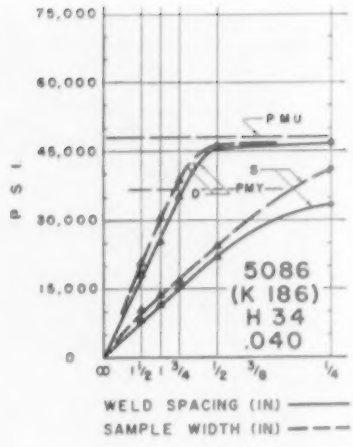


FIG. 26

Figs. 24–27 *Joint strength vs. weld spacing for four types of spot-weld specimens: single-spot, single-row panel joint, double-spot and double-row panel joint. Width of the single- and double-spot specimens is plotted on the same abscissa as weld spacing for the panel joint specimens. Welds were made in a range of thicknesses in 5086-H34 and 2024-T3 as indicated on the charts*

panels expressed as psi of specimen cross section. The dashed curves marked *S* illustrate the effect of specimen width. The data is taken from single-spot controlled-width specimens and is expressed as psi of specimen cross section. The two top curves present the same data for two-row spot patterns.

Compare the bottom curve of each figure. These show the results obtained from the single-row panel specimens. In most cases the curve for alloy 5083 is nearly flat between weld spacing $^1/_2$ and $^1/_4$ in. whereas the curve for alloy 5086 continues to rise in this region. This difference is consistent throughout all corresponding tempers of alloys 5083 and 5086 but no satisfactory explanation has been found for this behavior. Single-row panel joints in 2024-T3 reached a strength of nearly 30,000 psi at $^1/_4$ in. spacing. Equally good results were obtained with all tempers of alloy 5086 even though all tempers of alloy 5086 have a much lower ultimate strength than 2024-T3. The strength of single-row panel joints in alloy 5083 was slightly lower than those of alloys 5086 and 2024, the lowest joint in the series reaching 25,000 psi.

It is interesting to note that the two-row joints in tempers H32 and H34 of alloy 5083 exceeded the yield strength of the material. Two-row joints in all tempers of 5086 also exceeded parent metal yield strength. In many of these specimens Lueders' lines formed in the parent metal prior to fracture. This is a rather unusual occurrence in spot-welded joints.

In each case, the distance between the curve representing the panel specimens and the curve for controlled width specimens is a good indication of the strength loss due to shunting. If we were to compensate for shunting by increasing the welding current at closer weld spacings, single-row joint strength should approach that obtained from the specimens of controlled width and joints of nearly 40,000 psi should be realized. In this series of single-row tests, the 5086 alloy joints were somewhat superior to the 5083 alloy joints and both types reached the same strength region as 2024-T3 alloy joints.

In the two-row joints a greater difference is evident for various alloys and tempers. This is to be expected because the strengths of the joints begin to approach the ultimate tensile strength of the material. Alloy 2024-T3 with its higher ultimate parent metal strength gives a joint approaching 56,000 psi. Alloy 5083-H116 reached 55,000 psi although its parent metal strength is 4000 psi lower than that of 2024-T3.

Examining the curves for the double-row specimens of controlled width in Figs. 13 to 23 it appears that shunt compensation by increasing the current would result in only slight improvement in the 5083 joints and negligible improvement in the case of 5086. This is not surprising since the double row joints in the closer weld spacings, where shunting begins to be a problem, are already approaching parent metal strength and weld shear strength becomes a much less critical joint strength factor.

Effect of Sheet Thickness on Spot Welds in Alloy 5086

In the second series similar tests were made on 5086-H34 sheet having thicknesses of 0.020, 0.032, 0.040 and 0.091 in. Grain or rolling direction was parallel to the long axis of the final specimen throughout this series. The results are shown in Figs. 24 to 27.

Although the grain direction was not the same for the data of Fig. 23, the alloy and temper were identical, and they can be considered with the data of the second series. In the single-row panels it will be noted that

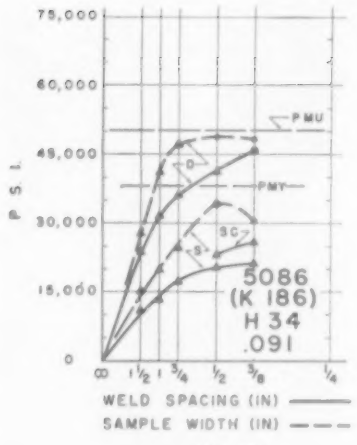


FIG 27

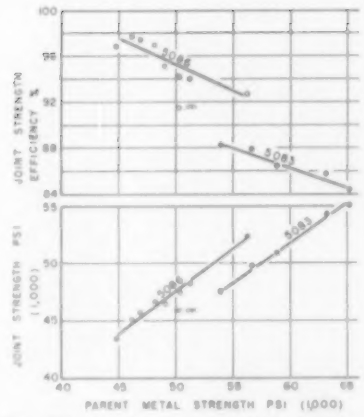


Fig. 28 Best two row joints, showing variation of joint strength and joint efficiency as a function of parent metal strength

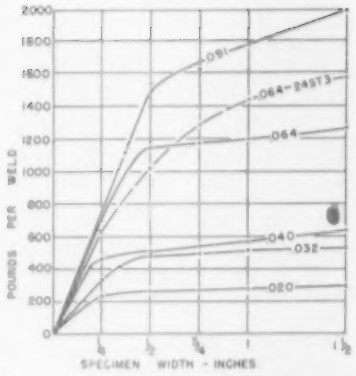
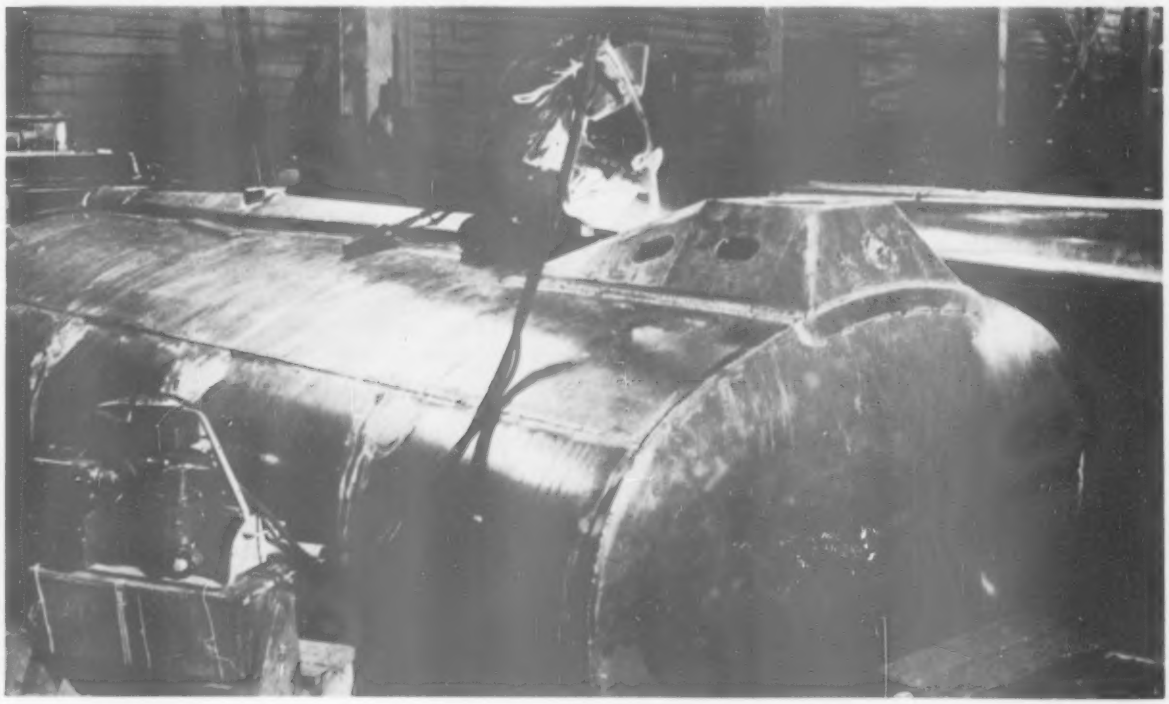


Fig. 29 Effect of specimen width on single spot shear strength for 5086-H34 in various gages

the highest strength was reached in 0.020-in. sheet and that there was a decrease in strength (psi of specimen cross section) as the specimen thickness increased. Two points in Fig. 27 marked *SC* represents an attempt at shunt compensation by means of increasing welding current. Shunt loss in the single-row joints was least noticeable in 0.020-in. sheet and increased with the heavier gages as shown by the increasing separation of the chain and solid curves. All two-row joints in this series reached at least 45,000 psi and except for the 0.091-in. sheet, shunt compensation in the two-row joint would result in only slight strength gain. Higher strength single-row joints could also be developed in 0.091-in. sheet panels by the use of higher currents for shunt compensation.

Figure 28 is a summary of the data on the highest strength two-row panel joints in 5083 and 5086 alloys. In alloy 5086 the data includes variations of temper as

Fig. 30 Inert-gas metal-arc welding of gasoline trailer tanks at Beall Pipe and Tank Corp., Portland, Ore. Tanks are fabricated of 5086 (K186) alloy using 5056 (56S) filler wire



creased payload of about 450 lb. Welding is done with 5056 filler wire throughout.

3. Design stresses allowable for arc-welded structures in 5083 and 5086 are 30 to 40% higher than those

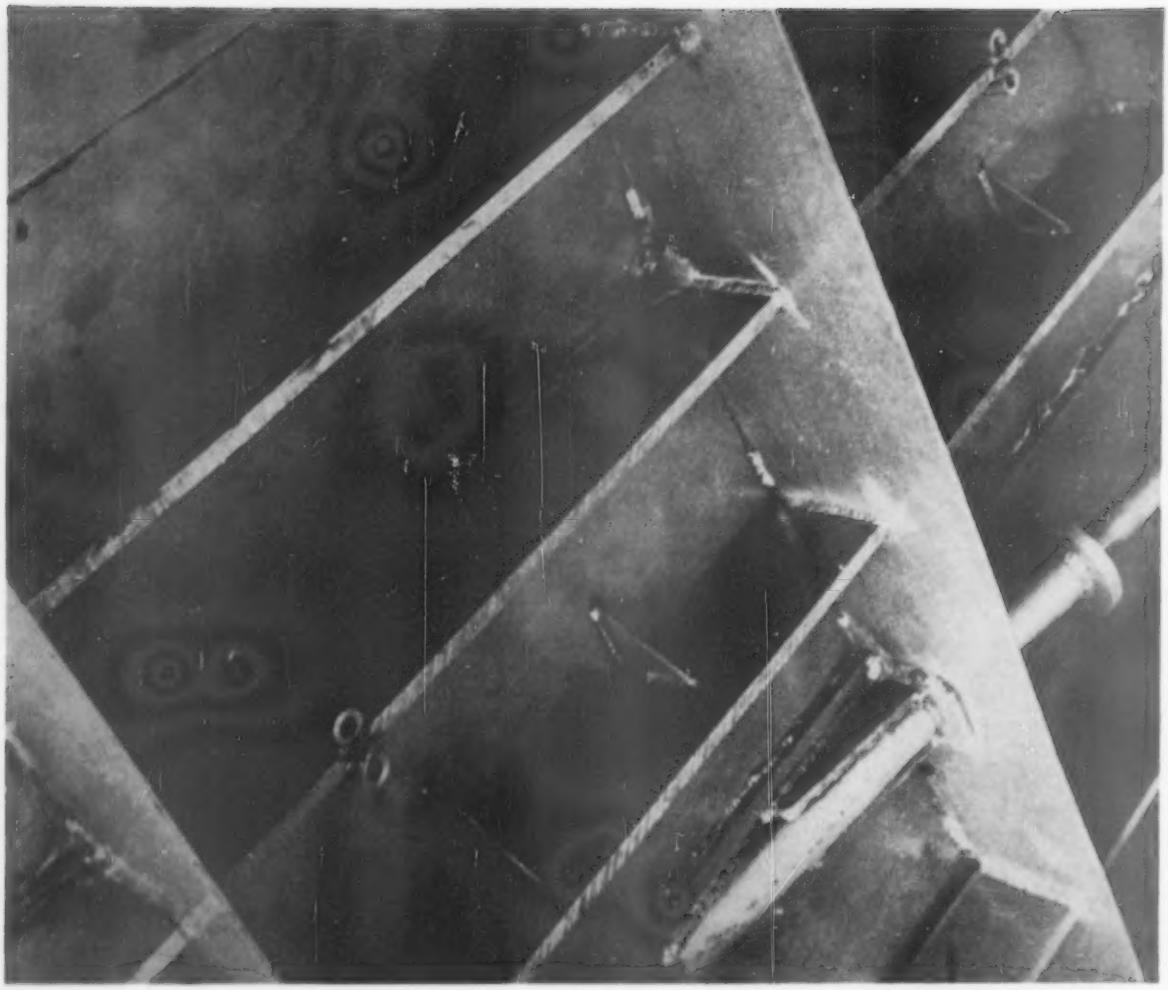


Fig. 31 Interior hull assembly of welded 40-ft crew boat. This crew boat was fabricated of alloy 5083 by Brauer Engineering Co., Corpus Christi, Tex.

well as thickness. Except for joints in 0.091-in. material, a straight line relation is indicated between parent metal strength and weld strength or joint efficiency. The two methods of expressing joint strength clearly demonstrate an inverse relation between joint strength and joint efficiency as the parent plate strength increases. Extrapolation of the 5086 efficiency curve to 100% indicates a parent metal strength of 40,000 psi which is the ultimate strength of annealed 5086. A similar extrapolation on the 5083 curves indicates that an efficiency of about 96% would be expected on annealed 5083 material which, for the lot of material tested, had an ultimate strength of 47,000 psi. Since no annealed material was included in the spot welding program, these extrapolations are merely predictions of what might be expected.

In Fig. 29 the data for single-weld specimens of controlled width is plotted to show the variation of the strength of single-spot welds with varied specimen width for the different gages of 5086 in the H34 condition. The curve for 0.064 in. 2024-T3 is included for comparison. The chief point to be noted in this plot is the contrast of curve shape for the two alloys. Additional studies showed that the curve shape is typical of alloy 5086 in all tempers but that alloy 5083 gives a curve similar to that of alloy 2024-T3. The importance of specimen width control in single spot weld test is evident from a study of Fig. 29.

Applications

An excellent application of 5086 alloy has been the construction of gasoline tank trailers* illustrated in Fig. 30 and in the lead illustration of this article. These tanks are easily formed, using inert-gas-shielded metal-arc welding. Service experience to date indicates that these tanks are more durable and have higher fatigue strength than tanks made previously of 5052 alloy. Using 5086 alloy it has been possible to reduce the weight of the tank by 10% thus allowing an in-

* Beall Pipe and Tank Corp., Portland, Ore.

creased payload of about 450 lb. Welding is done with 5056 filler wire throughout.

Another application is the use of alloy 5083 for fabricating crew boats* as illustrated in Figs. 31 and 32. The boat is 40 ft long with a 13-ft 4-in. beam, a 58-in. freeboard and a draft of 2 ft 10 in. Hull plates are $^1/_4$ in. thick. All welding was done with $^1/_{16}$-in. diam 5056 filler wire using the inert-gas metal-arc process. Welding characteristics were excellent and no appreciable warping was encountered. The entire boat, less engines, weighs about 9500 lb and is designed to cruise at 30 mph. Figure 31 shows the interior of the welded hull assembly. Keelson and engine stringers are fabricated of 5083 $^3/_4$-in. plate. Figure 32 is a bow-on view of the crew-boat hull.

Conclusions

1. High as-welded joint efficiencies of 80 to 100% can be obtained in assemblies of 5086 or 5083 alloys joined by inert-gas arc welding or spot welding.

2. Design stresses for loads transverse to the weld bead of arc-welded assemblies must be based on the strength of the annealed base plate. When design is based on ultimate strength, typical values for welded joints are 42,500 psi for 5083 and 38,700 psi for 5086.

3. Design stresses allowable for arc-welded structures in 5083 and 5086 are 30 to 40% higher than those for 6061 and 5052.

4. Both the weld metal and heat-affected zones in the base plate of 5083 and 5086 alloys have excellent ductility.

5. The metallurgical notch for welds in 5083 and 5086 alloys is less severe than in most other commercial alloys.

6. The most significant static mechanical tests for aluminum welds consist of:

(*a*) Standard transverse tensile tests for ultimate tensile strength only.

(*b*) Substandard tensile tests conducted on specimens cut parallel to the weld bead and taken in the weld metal and immediately adjacent to the weld metal.

7. Hardness surveys across the weld metal and for 1 in. on either side of it give an excellent indication of the extent and magnitude of the heat-affected zone.

8. The tensile strength of single-row spot-welded joints in 5083 and 5086 approach the strength of similar joints in 2024-T3. In close spacings, single-row spot-welded joints in 5086 are stronger than those in 2024-T3.

9 The strength of two-row spot-welded joints approaches the yield strength of the parent material in harder tempers of 5083 alloy. In the softer tempers of 5083 and in all tempers of 5086 the strength of two-row spot-welded joints exceed the yield strength of the parent material. In harder tempers of 5083 the strength of two-row spot-welded joints approaches that obtained in 2024-T3.

10. In common with other aluminum alloys, 5086 shows higher shunt loss for spot-welded panels in heavier gages.

11. Expression of joint strength in terms of efficiency can be misleading for high-strength, spot-welded joints of various tempers, since the most efficient joints do not have the highest strength.

Acknowledgment

The authors express their appreciation for the valuable assistance of several research technicians and particularly of J. Casey, A. Dolomont, S. St. Denis and H. B. Mathes and N. E. Whitford.

* Brauer Engineering Co., Corpus Christi, Tex.

Fig. 32 Bow-on view of aluminum 40-ft crew boat. This boat was fabricated of alloy 5083 using 5056 filler wire and inert-gas metal-arc welding. Photo courtesy Brauer Engineering Co., Corpus Christi, Tex.

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MECHANICAL PROPERTIES OF WELDED 356 ALUMINUM CASTINGS

Investigation indicates that, with proper postweld heat treatment, 356 aluminum alloy castings can be repaired without loss in strength. Also, it is feasible to design production parts from weldments composed of castings or of cast and wrought aluminum alloy sections

BY WALTER S. TENNER

ABSTRACT. The welding together of aluminum castings or cast sections with wrought sections can often save weight and simplify the fabrication of complex shapes. Although 356 aluminum is considered a weldable alloy, design engineers seldom take advantage of welding techniques because the mechanical properties of such weldments have not been sufficiently investigated.

In order to obtain these data, a series of specimens, $^1/_4$, $^1/_2$ and 1-in. thick, were welded together, using various filler rods and heat treatments. These weldments were radiographed and tested for tensile strength and ductility, with the following results:

1. Joint efficiencies of 100% can be obtained when $^1/_4$-in.-thick 356 aluminum alloy castings are welded, using 5% silicon, 11% silicon or 356 aluminum alloy filler rods, provided the weldments are heat treated after welding to the T-6 condition.
2. Joint efficiencies of 100% can be obtained when $^1/_2$- and 1-in.-thick castings are welded with 356 filler rod, provided the castings are heat treated after welding to the T-6 condition.
3. All 356 aluminum alloy weldments tested in the as-welded condition failed in the heat-affected zone, regardless of the filler rod used, but joint efficiencies ranging from 50 to 75% were obtained.
4. Castings of 356 aluminum alloy can be readily welded to 618T wrought aluminum, producing joint efficiencies of 100% based on the strength of the casting, provided the weldments are heat treated after welding.
5. Castings of 356 aluminum alloy can be successfully repaired without loss in strength, if the weldments can be heat treated subsequent to welding.

The author believes that the mechanical properties of the weldments tested indicate that welding could be used more frequently for repairing defective castings and fabricating complex shapes.

Introduction

A large percentage of the aluminum alloy castings produced at the Naval Ordnance Test Station are made from 356 aluminum alloy which contains approximately 7.0% silicon and 0.3% magnesium. This alloy is relatively easy to cast, has excellent corrosion resistance and produces castings that are relatively pressure tight. The minimum mechanical properties required for 356 aluminum alloy are, according to Government specifications AN-A-39, 30,000 psi ultimate strength and 3.0% elongation in 2 in. for sand-cast bars heat treated to T-6 condition, 22,000 psi ultimate strength and 0.7% elongation for machined test bars.

The 356 aluminum alloy castings produced at the Naval Ordnance Test Station are often large and intricate in design. Occasionally a radiograph reveals small defective areas which call for repair or rejection of the casting. Although 356 aluminum alloy is considered a weldable alloy, design engineers have been reluctant to use castings repaired in critical areas, because little was known about the mechanical properties of the weld areas.

The purpose of this investigation was (1) to determine the mechanical properties that could be expected from weldments of 356 aluminum alloy obtained by specified welding procedures; (2) to determine the feasibility of fabricating finished parts by welding together cast or cast-and-wrought aluminum alloy components. Welding often saves weight and permits the fabrication of complex shapes which are difficult and expensive to cast as single units. Although ferrous alloys are fabricated extensively in this manner, designers have not taken full advantage of this technique when dealing with aluminum alloys.

This investigation was divided into four phases: (1) evaluation of single-pass welds in $^1/_4$-in.-thick castings; (2) evaluation of multiple-pass welds in $^1/_2$-, $^3/_4$- and 1-in.-thick castings; (3) evaluation of weldments made from cast and wrought aluminum alloys; (4) evaluation of a component fabricated by welding together cast-356-aluminum-alloy sections.

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erties; all the others showed somewhat lower ultimate

Fabrication of an ordance component by welding

Although 356-aluminum-alloy castings should be heat treated after welding to obtain optimum mechanical properties, there are many instances where this cannot be done: for example, when a defect is exposed after a casting has been almost fully machined, or when parts, fabricated by welding, cannot be heat treated because of distortion. It was therefore important to investigate also the mechanical properties of weldments in the as-welded condition.

Casting Procedure

In order to produce castings of relatively uniform quality a consistent melting and casting procedure was first established. All castings were made from virgin aluminum alloy pig. Each cast plate was radiographed to make certain that only quality castings were used. The center riser section was saw-cut from each casting, furnishing two test plates. The saw-cut edges were butt welded together.

Welding Equipment and Procedures

The equipment was typical of that used in most foundries: a 300-amp water-cooled inert-gas tungsten-arc torch, whose power was supplied by a 400-amp a-c transformer with built-in high frequency. High-thoria-tungsten electrodes and argon gas were used throughout.

Three different filler rods were tried: aluminum with 5% silicon, aluminum with 11% silicon and 356 aluminum alloy. The 5% silicon filler rod, the most widely used, is a weak, nonheat-treatable aluminum alloy, but has excellent fluidity. The 11% silicon filler rod is primarily a brazing alloy. Its mechanical properties are superior to those of the 5% silicon alloy and its fluidity is excellent, but it is also nonheat-treatable. The 356-aluminum-alloy filler rods were used in order to realize maximum strength from the postheat treatment of the weldments. At first these rods were made by cutting $\frac{1}{8}$-in.-wide strips from a $\frac{1}{4}$-in.-thick cast plate. Later $\frac{3}{16}$-in.-diam filler rods, 18 in. long, were cast in a permanent mold. All filler rods were degreased and cleaned with steel wool prior to welding.

All-weld-metal tensile specimens were made from each of the three kinds of filler rods. Test results are the average of three specimens and are shown on next page:

	Ultimate strength, psi	*Yield strength, psi, 0.2% offset*	*Elongation % in 2 in.*
5% Si	20,500	8,210	19.2
11½% Si	24,500	10,400	18.0
356 (as-welded)	24,350	11,350	10.4
356 T-6	43,150	33,700	6.1

The 356 T-6 specimens had excellent mechanical properties; all the others showed somewhat lower ultimate strength and very low yield strength. A chemical analysis of the specimens indicated an insignificant amount of alloy loss. All three filler rods had excellent welding characteristics, but the cast 356 filler rods caused occasional difficulties due to dross or oxide inclusions.

Prior to welding, the cast plates were cleaned with a disk sander, degreased and clamped to a grooved stain-

Welded ¼" thick 356 Aluminum Alloy Cast Plates

	5% Si Filler Rod[1]	Base Metal Specimens[2]	11.5% Si Filler Rod[1]	Base Metal Specimens[2]	7% Si .30% Mg Filler Rod[1]	Base Metal Specimens[2]
Specimens welded in the T-6 condition and tested in the as-welded condition						
Tensile Tests[3]						
Ult. Str. psi	24,300	35,600	22,000	31,900	24,700	36,100
Yield Str. psi	15,300	28,400	17,000	22,900	16,200	29,700
%Elongation in 2"	3.0	1.75	2.8	1.8	2.7	2.0
Base Metal Bend Tests						
Angle of Bend		3°		6°		3°
Elongation[4]		.....		.....		.....
Face Bend Tests						
Angle of Bend	22°		18.5°		17°	
%Elongation in Weld	10.0		10.0		5.0	
Root Bend Tests						
Angle of Bend	18°		12.5°		16.5°	
% Elongation in Weld	11.0		7.0		7.0	
Specimens welded in the T-6 condition and heat treated to the T-51 condition after welding						
Tensile Tests[3]						
Ult. Str. psi	21,500	24,700	24,700	27,800	21,200	22,500
Yield Str. psi	17,900	21,100	18,400	25,700	17,200	19,700
% Elongation in 2"	2.0	1.3	1.8	1.3	1.8	1.5
Base Metal Bend Tests						
Angle of Bend		2.5°		11.5°		2°
Elongation[4]		.....		.....		.....
Face Bend Tests						
Angle of Bend	11°		12°		10°	
% Elongation in Weld	5.0				5.0	
Root Bend Tests						
Angle of Bend	8.5°		11°		7°	
% Elongation in Weld	4.0				4.0	
Specimens welded in the T-6 condition and heat treated to the T-6 condition after welding						
Tensile Tests[3]						
Ult. Str. psi	37,200	37,900	32,700	35,700	41,000	37,400
Yield Str. psi	32,500	34,400	30,100	31,500	35,900	34,800
% Elongation in 2"	1.3	2.3	1.8	2.0	1.8	..... [4]
Base Metal Bend Tests						
Angle of Bend		2.5°		3°		3°
Elongation[4]		.....		.....		.....
Face Bend Tests						
Angle of Bend	14.5°		21°		13°	
% Elongation in Weld	11.0		11.0		8.0	
Root Bend Tests						
Angle of Bend	11.5°		11.5°		16.5°	
% Elongation in Weld	6.0		3.0		11.0	
Specimens welded in the as-cast condition and heat treated to the T-6 condition after welding						
Tensile Tests[3]						
Ult. Str. psi	34,500	33,500	36,100	36,600	36,900	37,700
Yield Str. psi	27,900	29,300	29,400	29,000	34,800	35,500
% Elongation in 2"	2.0	1.3	2.5	2.8	1.0	.5
Base Metal Bend Tests						
Angle of Bend		6°		12°		3°
Elongation[4]		.....		.....		.....
Face Bend Tests						
Angle of Bend	28.5°		32°		12°	
% Elongation in Weld	13.0		14.0		7.0	
Root Bend Tests						
Angle of Bend	16°		17.5°		15°	
% Elongation in Weld	8.0		7.0		7.0	

[1] Values are the average of three specimens
[2] Values are the average of two specimens
[3] Welded specimens all broke outside weld area
[4] Not specified. The error in determining elongations of 1 percent or less is comparable to the value being measured.

Table 1—Tensile and Bend Test Results

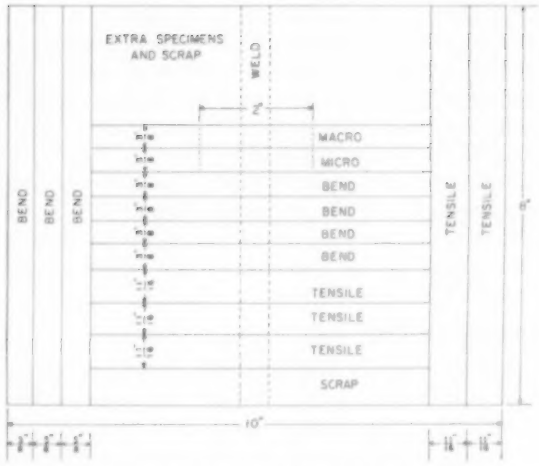


Fig. 1 Lay out of weld joints, $^1/_4$-in. thick castings

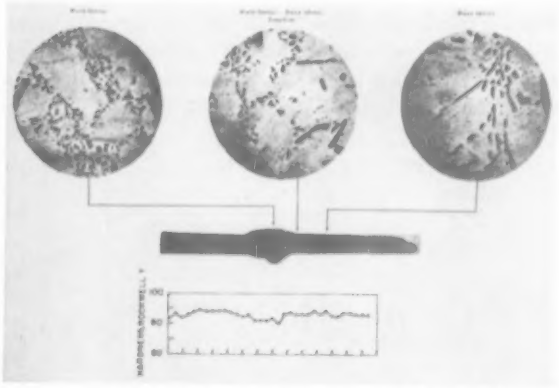


Fig. 2 Photomicrographs (magnification × 500) and hardness survey of specimen heat treated to the T-6 condition after welding. (Reproduction reduced by two-thirds)

less-steel backing plate. Single-pass welds were made with the $^1/_4$-in.-thick castings, using a closed square butt joint. Single-vee butt joints with a $^1/_8$-in. root opening were used with the $^1/_2$-in.-thick castings. Single- and double-vee joints with a $^1/_8$-in. root opening were used with the 1-in.-thick castings. All weld joints were radiographed to determine the weld quality.

Testing of the $^1/_4$-In.-Thick Castings

A separate test panel was made for each set of conditions. Test specimens were cut from the $^1/_4$-in. weldments as shown in Fig. 1. Tensile and bend specimens of the parent metal of each casting were tested as controls. The weld reinforcement was machined off in all the butt joints tested. The welding and heat treating procedures with tensile- and bend-test results are shown in Table 1. Test results indicate that joint efficiencies of approximately 100% can be obtained with any of the three filler rods, provided the weldments are heat treated to the T-6 condition subsequent to welding. Apparently in a single-pass weld, using a closed square butt joint, sufficient dilution of the base metal occurs to give the deposited metal the magnesium content it needs to be heat-treatable. No difference in tensile properties was noted between castings welded in the as-cast and those welded in the T-6 condition, provided the weldments were heat treated to the T-6 condition afterward. Weldments tested in the as-welded condition had joint efficiencies of approximately 60% with all three filler rods.

Castings were welded in the T-6 condition and then heat treated to the T-51 condition, in an attempt to improve the as-welded properties of the weldments without resorting to a re-solution heat treatment. Test results indicate, however, that this did not improve the mechanical properties of the weld area, while impairing the mechanical properties of the casting outside the weld area. Bend-test results of the $^1/_4$-in.-thick weldments showed the weld in every instance to be more ductile than the base metal.

Photomicrographs and hardness of a weldment tested in the T-6 condition are shown in Fig. 2. This casting was welded with 356 filler rod. The weld area of the specimen is of uniform hardness and microstructure. Figure 3 shows the weld area of a weldment tested in the as-welded condition. The weld area of this specimen is not of uniform hardness and microstructure, but shows four distinct zones: cast zone, partially fused zone, heat-affected zone, and unaffected zone. The cast zone consists of deposited metal and metal melted from the shoulders of the casting. This area has a finer grain structure than the base metal. The partially fused zone (area immediately adjacent to the weld) has a microstructure similar to as-cast 356 aluminum alloy. The heat-affected zone shows a coalescence of the precipitate, forming comparatively large aggregates similar to overaged 356 aluminum alloy, which materially reduces the hardness. The as-welded tensile specimens failed in this overaged area. All tensile specimens tested in the T-6 condition failed outside the weld area.

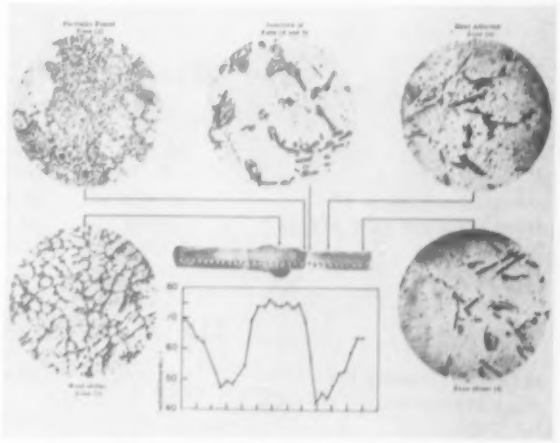


Fig. 3 Photomicrographs (magnification × 500) and hardness survey of specimen tested in the as-welded condition. (Reproduction reduced by two-thirds)

Testing of the $^1/_2$- and 1-In.-Thick Castings

The layout used for the $^1/_2$- and 1-in.-thick castings is shown in Fig. 4. Since wider specimens were used, the number of specimens per casting was smaller. The size of the castings was not increased because the probability of obtaining good uniformity is better with small castings. The bend tests were omitted because the angle of bend would have been too low to yield significant data. Again a separate test panel was made for each set of conditions.

Tensile-test data of weldments made from $^1/_2$-in.-thick castings are shown in Table 2. They indicate that joint efficiencies of 100% can be obtained when 356 filler rod is used, provided the weldments are heat treated to the T-6 condition after welding. Joint efficiencies of approximately 74% were obtained with either 5% silicon or 11.5% silicon filler rods when the weldments were heat treated, but the yield strengths were very low. In butt joints made of thicker castings with beveled edges the filler metal used is an important factor. In the as-welded condition, all three filler rods yield joint efficiencies of approximately 63%.

Tensile-test data of weldments made from 1-in.-thick castings are shown in Table 3. With 356 aluminum filler rod the joint efficiencies were the same as those obtained with $^1/_2$-in.-thick castings. With 5% silicon filler rod, the joint efficiencies were approximately 69% and with 11.5% silicon filler rod approximately 75%, after heat treatment to the T-6 condition. No difference in tensile properties was noted between castings welded in the as-cast and those welded in the T-6 condition, if the weldments were heat treated to the T-6 conditions after welding.

Regardless of the filler rod used, specimens welded in the T-6 condition using 600° F preheat, and tested in the as-welded condition, had tensile properties approximating 50% of the minimum values specified in Government Specification AN-A-39. The tensile strength of the casting outside the weld area was reduced to about 56% of the minimum values specified for 356 T-6. When a preheat of 300° F. was used, the tensile strength within as well as outside the weld area was 60% of the minimum values specified for 356 T-6 castings, regardless of the filler rod used. The specimens tested in the as-welded condition all failed in the heat-affected zone in the overaged area. Apparently the deposited metal has greater strength than the heat-affected zone or overaged area of the casting, regardless of the filler metal used. Double-vee joints, made to determine the effect of joint design on the tensile strength of the weldments, had approximately the same tensile properties.

Welding of Cast and Wrought Parts

To determine the properties that could be expected when cast and wrought aluminum alloys are welded together, weldments were made from cast 356 and wrought 61ST aluminum alloys. The latter was selected because its welding characteristics and heat treatment are quite similar to those of 356 aluminum alloy. First of all, a heat treatment had to be found that would result in maximum properties for the 356 cast-aluminum alloy without overheating the 61ST wrought-aluminum alloy. Experiments led to a compromise consisting of a solution heat treatment at 970° F for 12 hr and a pre-

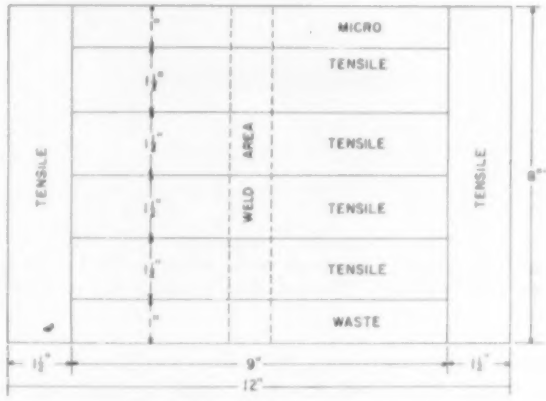


Fig. 4 Layout of weld joints $^1/_2$- and 1-in. thick castings

SPECIMENS WELDED IN THE AS CAST CONDITION AND HEAT TREATED TO THE T-6 CONDITION AFTER WELDING

	5% SI FILLER ROD	BASE METAL SPECIMENS	11 1/2% SI FILLER ROD	BASE METAL SPECIMENS	356 FILLER ROD	BASE METAL SPECIMENS
ULTIMATE STRENGTH PSI	19,700	27,500	20,600	27,500	33,200	33,600
YIELD STRENGTH 0.2% OFFSET	16,500	26,500	16,500	—	28,100	28,600

SPECIMENS WELDED IN THE T-6 CONDITION AND TESTED IN THE AS WELDED CONDITION 300°F PREHEAT

ULTIMATE STRENGTH PSI	18,800	25,800	18,300	27,200	20,200	20,500
YIELD STRENGTH 0.2% OFFSET	—	—	16,400	—	13,800	—

● TEST RESULTS ARE THE AVERAGE OF FOUR SPECIMENS

Table 2—Tensile Test Results● Welded $^1/_2$-In. Thick 356 Aluminum Alloy Cast Plate Using Single-V Joint Design

SINGLE V WELD

SPECIMENS WELDED IN T-6 CONDITION USING 600°F PREHEAT AND TESTED IN THE AS WELDED CONDITION

	5%Si Filler Rod	Base Metal	11-1/2%Si Filler Rod	Base Metal	356 Filler Rod	Base Metal
TENSILE TESTS						
Ult. Str. psi	14,200	17,400	14,700	16,800	14,170	15,800
Yield Str. psi 0.2% Offset	7,800	11,000	9,600	9,800	8,950	9,100

SPECIMENS WELDED IN T-6 CONDITION USING 300°F PREHEAT AND TESTED IN THE AS WELDED CONDITION

	5%Si Filler Rod	Base Metal	11-1/2%Si Filler Rod	Base Metal	356 Filler Rod	Base Metal
	18,300	25,200	19,800	29,500	18,600	29,100
	12,200		13,800		12,300	

SINGLE V WELD

SPECIMENS WELDED IN THE AS CAST CONDITION AND HEAT TREATED TO THE T-6 CONDITION AFTER WELDING

	5%Si Filler Rod	Base Metal	11-1/2%Si Filler Rod	Base Metal	356 Filler Rod	Base Metal
TENSILE TESTS						
Ult. Str. psi	19,345	28,890	21,000	27,800	31,200	29,300
Yield Str. psi 0.2% Offset	14,200	29,725	13,000	24,800		

SPECIMENS WELDED IN THE T-6 CONDITION AND HEAT TREATED TO THE T-6 CONDITION AFTER WELDING

	5%Si Filler Rod	Base Metal	11-1/2%Si Filler Rod	Base Metal	356 Filler Rod	Base Metal
	18,400	22,300	22,830	29,000	29,550	31,300
	11,830		14,150	27,500		

DOUBLE V WELD

SPECIMENS WELDED IN THE AS CAST CONDITION AND HEAT TREATED TO THE T-6 CONDITION AFTER WELDING

TENSILE TESTS	5%Si Filler Rod	Base Metal	11-1/2%Si Filler Rod	Base Metal	356 Filler Rod	Base Metal
TENSILE TESTS						
Ult. Str. psi	18,600	26,700	20,700	26,800	28,900	30,000
Yield Str. psi 0.2% Offset	13,800		14,500	21,500		

SPECIMENS WELDED IN T-6 CONDITION USING 300°F PREHEAT AND TESTED IN THE AS WELDED CONDITION

	5%Si Filler Rod	Base Metal	11-1/2%Si Filler Rod	Base Metal	356 Filler Rod	Base Metal
	18,100	25,600	17,850	19,300	19,400	23,700
	11,400		13,100		11,800	

@ TEST RESULTS ARE THE AVERAGE OF FOUR SPECIMENS

Table 3—Transverse Butt Weld Tensile Test Results,* 1 In. Thick Castings

SPECIMENS HEAT TREATED TO THE T-6 CONDITION AFTER WELDING

	5% SI FILLER ROD	BASE METAL (CASTING) SPECIMENS
ULTIMATE STRENGTH PSI	34,160	33,900
YIELD STRENGTH 0.2% OFFSET	30,720	27,800

SPECIMENS WELDED IN THE T-6 CONDITION AND TESTED IN THE AS WELDED CONDITION (300°F PREHEAT)

	5% SI FILLER ROD	BASE METAL (CASTING) SPECIMENS
ULTIMATE STRENGTH PSI	24,530	33,900
YIELD STRENGTH 0.2% OFFSET	17,770	27,800

Table 4—Tensile Test Results of Butt Welds, $^1/_4$-In. Thick Castings—$^1/_4$-In. Thick Wrought 61ST Alloy

SPECIMENS HEAT TREATED TO THE T-6 CONDITION AFTER WELDING

	5% Si FILLER ROD	BASE METAL (CASTING) SPECIMENS	11 1/2% Si FILLER ROD	BASE METAL (CASTING) SPECIMENS	356 FILLER ROD	BASE METAL (CASTING) SPECIMENS
ULTIMATE STRENGTH PSI	25,060	25,250	29,770	30,690	28,000	27,300
YIELD STRENGTH 0.2% OFFSET		24,000	28,900	28,210	25,850	

SPECIMENS WELDED IN THE T-6 AND TESTED IN THE AS WELDED CONDITION (300°F PREHEATED)

ULTIMATE STRENGTH PSI	22,170	32,900	24,700	33,000	22,170	31,100
YIELD STRENGTH 0.2% OFFSET		32,200		31,600		

♦ TEST RESULTS ARE THE AVERAGE OF FOUR SPECIMENS

Table 5—Tensile Test Results* of Butt Welds, 3/4-In. Thick 356 Castings—3/4-In. Thick Wrought 61ST Alloy

cipitation treatment at 320° F for 12 hr. This heat treatment was applied to all subsequent weldments made from 356 and 61ST aluminum alloys which were heat treated after welding. Tensile-test data of butt joints made from 1/4-in.-thick 356 castings and 61ST aluminum alloy are shown in Table 4. All specimens were welded with 5% silicon filler rod, because previous experiments with 1/4-in.-thick castings had indicated that all three filler rods were equivalent. Joint efficiencies of 100% after heat treatment were obtained, and fractures originated in the casting portion of the weldments, outside the weld area. In the as-welded condition, the joint efficiencies were approximately 73%, with fractures occurring in the casting portion of the weldments, in the heat-affected zone.

Tensile-test data of 3/4-in.-thick specimens machined from butt joints of 356 castings with 61ST aluminum alloys are shown in Table 5. They indicate a joint strength equivalent to that of parent 356 castings, regardless of the filler rod used, if the weldments are heat treated after welding. Apparently the dilution from the 61S aluminum alloy is sufficient to give the deposited metal ample magnesium content to be heat-treatable. The weldments all failed in their casting portion, outside the weld area. The specimens tested in the as-welded condition had joint efficiencies of approximately 68% for all three filler rods, and they all failed in the heat-affected zone of the casting portion.

Fillet Joints Between Castings and Wrought Aluminum

There are many instances when ordnance components could be fabricated by using fillet joints between castings and wrought aluminum alloy. In order to determine the mechanical properties of such joints, specimens simulating fillet welds were tested. The type of specimen used is shown in Fig. 5, and tensile-test data of fillet joints in Table 6. Joint efficiencies of approximately 100%, based on the strength of the 61S-T6 aluminum alloy, can be obtained with all three filler rods, if the weldments are heat treated. The specimens all fracture outside the weld

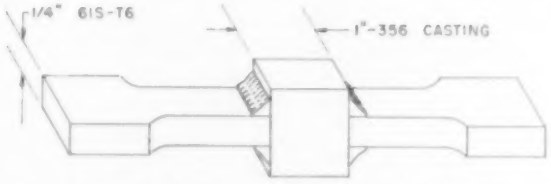
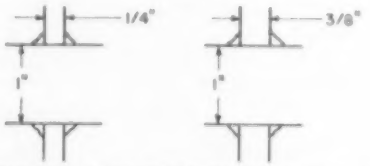


Fig. 5 Specimen of fillet joint, 61S-T6 and 356 casting



SPECIMENS HEAT TREATED TO THE T-6 CONDITION AFTER WELDING

Ultimate Strength psi	5% Si Filler Rod	11-1/2% Si Filler Rod	356 Filler Rod
1/4"	47,930	48,170	48,200
3/8"	46,570	47,570	47,670

SPECIMENS WELDED IN THE T-6 CONDITION AND TESTED AS WELDED (300°F PREHEAT)

Ultimate Strength psi	5% Si Filler Rod	11-1/2% Si Filler Rod	356 Filler Rod
1/4"	24,250	24,570	23,780
3/8"	23,900	23,130	23,130

* TEST RESULTS ARE THE AVERAGE OF FOUR SPECIMENS

Table 6—Tensile Test Results,* Fillet Joints, 356 Castings 61S Wrought Aluminum

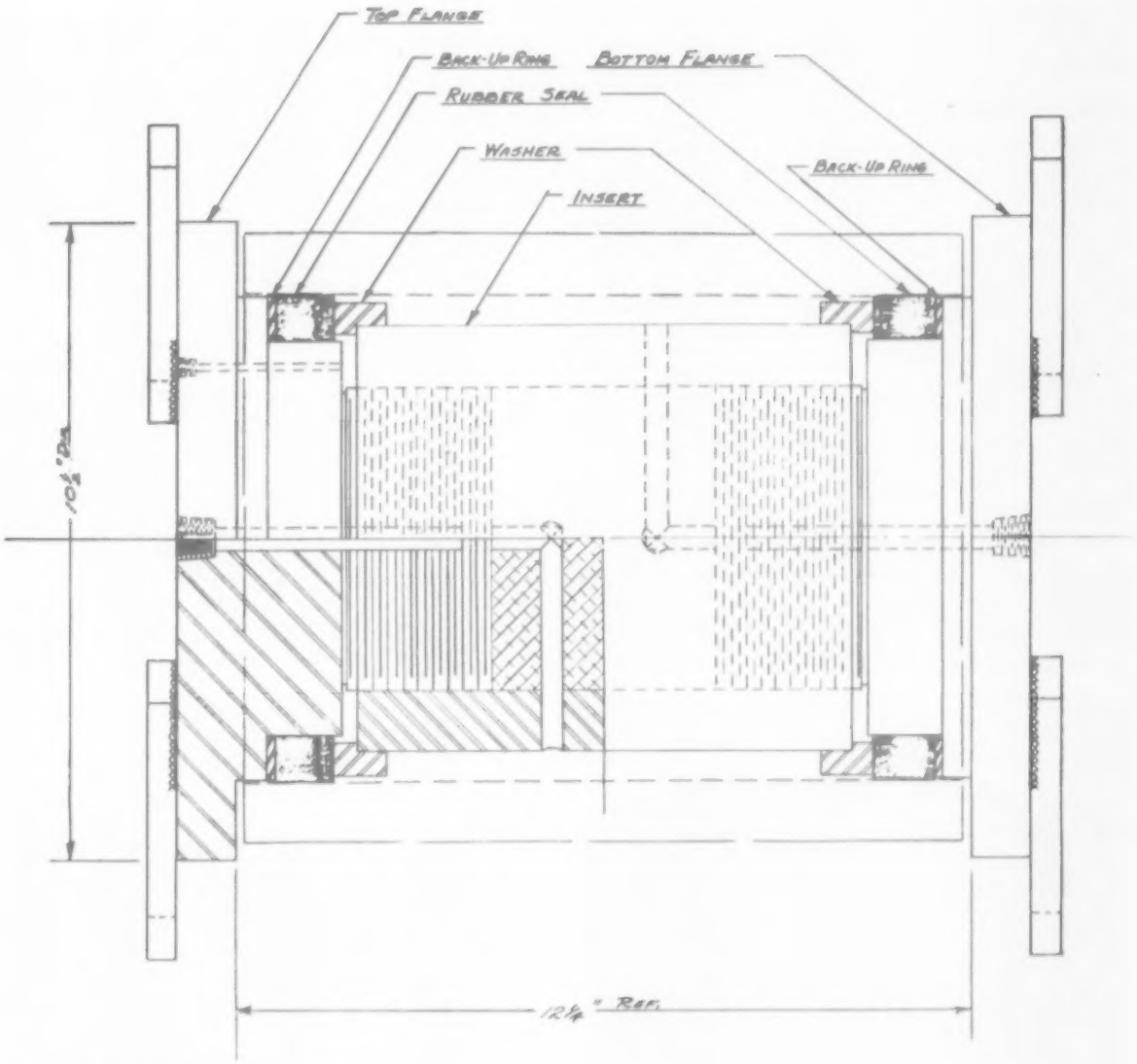


Fig. 6 Pressure-test fixture assembly

area. In the as-welded condition the joint efficiencies were 50% and all specimens fractured in the heat-affected zone of the 618 aluminum alloy.

Fabricating a Composite Shape

Up to this point, all the testing had been done with small tensile and bend specimens. The next step was to determine the mechanical properties of a simulated component fabricated by welding several castings together. A cylindrical shape was selected because it could be hydrostatically tested with a relatively simple test fixture, designed for this purpose and shown in Fig. 6. Its chief advantage is that the components do not have to be machined before testing. The only preparation necessary was the grinding of the inside diameter on each end of the cylinders to assure a seal with the rubber gaskets. Cylinders 9 in. O.D. and 12 in. high were cast from 356 aluminum alloy in $^3/_4$- and 1-in. thicknesses. The cylinders were all radiographed and only castings of the highest quality were selected for testing. Sample cylinders were then hydrostatically burst-tested to determine the typical strength of the castings. Similar cylinders were machined into four sections. A cross joint was selected because it is probably the severest test a weldment can be subjected to. The sections were welded together, using 356 filler rod, and the weldments were heat treated to the T-6 condition. The weld reinforcements were removed and the weldments then hydrostatically burst-tested. The test results are listed below and a typical fractured specimen is shown in Fig. 7.

Average Burst Test Results,* Cast and Welded Cylinders

1-in.-thick cast cylinders, stress psi	22,950
1-in.-thick welded cylinders, stress psi	23,150
$^3/_4$-in.-thick cast cylinders, stress psi	24,450
$^3/_4$-in.-thick welded cylinders, stress psi	26,300

* Average results of 3 specimens.

Joint efficiencies of 100% were obtained in all weldments, with failure initiating outside the weld area in all instances.

Repairing Defective Casting

Many defective 356-aluminum-alloy castings have been successfully repaired by welding at the Naval Ordnance Test Station. Unfortunately, most of the castings are classified and cannot be shown. Very little difficulty was encountered during this investigation in welding any of the 356-aluminum-alloy castings and radiographically sound welds were produced consistently. Sound welds were even made with gassy castings. Castings containing dross were the most difficult to weld, but dross can be successfully worked to the surface of the weld by manipulating the torch. No cracks due to welding were noted at any time during these experiments.

Conclusions

As a result of this investigation, two manufacturers are now commercially extruding 356-aluminum-alloy filler rods. This extruded wire is, of course, much simpler to use than the cast rods and has excellent fluidity. The Naval Ordnance Test Station production-shop welders prefer this filler rod to the 5% silicon rod.

The author believes that this investigation demonstrates the feasibility of designing production parts made by welding together castings or cast- and wrought-aluminum-alloy sections. The data are presented in the hope that design engineers will take advantage of this technique when they are faced with the problems of saving weight or fabricating complex shapes which are difficult and expensive to cast as single units.

Many of the tests performed during this investigation will be repeated using the inert-gas consumable-electrode type equipment. The technique will also be applied to other aluminum and magnesium casting alloys.

Acknowledgment

The author is indebted to Dom Veronda, Head, Materials and Process Section, for his help and support. Special acknowledgment is also due to H. C. Wheeler, mechanical engineer, John LaBosky, foundry metallurgist, Leo Maguire, metallographer, and Wilbur Foote, welder, for their splendid cooperation.

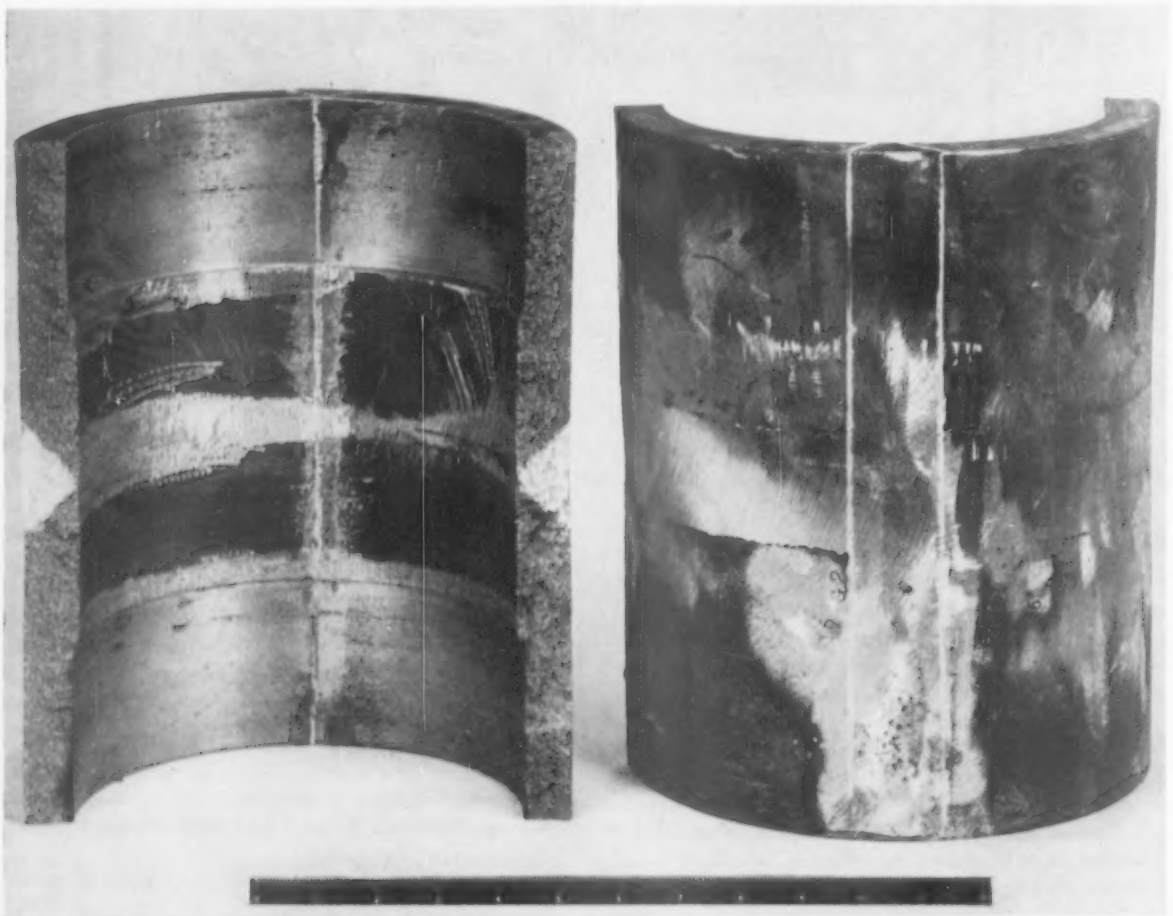


Fig. 7 Typical burst tested cylinder

Welding of truck bodies with inert-gas-shielded metal-arc welding

NEW TECHNIQUES IN INERT-GAS-SHIELDED METAL-ARC WELDING

Laboratory investigations indicate that, when proper techniques are employed with carbon dioxide as a shielding atmosphere, satisfactory welds can be produced at increased speeds and lower over-all welding costs

By R. W. TUTHILL

The potential widespread use of carbon dioxide gas as a protective atmosphere for gas-shielded consumable electrode welding of mild steel is of tremendous significance to the whole welding industry.

Applications of this welding process for mild steel using an inert gas shield have gone forward in spite of the relatively high gas costs. The rate of argon gas usage is approximately fifty cubic feet per hour, which makes the gas cost about five dollars per hour of arc time. However, the cost of electrode for this method of welding mild steel is approximately one dollar and fifty cents to two dollars per hour of arc time.

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Presented at the Thirty-Fifth AWS National Fall Meeting held in Chicago, Nov. 1–5, 1954.

It is easily seen that even though gas costs, like the cost of electrode, may be factored into the cost of a product as material, and not be multiplied by overhead, it can be and is a serious cost obstacle to the widespread application of this method of welding mild steel. In gas-shielded welding there is no flux, and consequently no slag, to produce inclusions or to remove after welding. This factor has probably been one of the most important in those applications of this process with expensive inert gases at the present time.

Economy of Process

It has long ago been recognized by many people that carbon dioxide alone would be a more economical shielding gas if ways could be found to utilize it effec-

tively. The most important factor with respect to the use of carbon dioxide is the low cost of shielding gas. Carbon dioxide is usually sold by the pound and the price is about eight cents a pound in 50-lb cylinders. The cost per cubic foot is about one cent. Beside the cost being less, it is quite feasible to weld with less quantity, 20-30 cfh being quite sufficient. The net result of both these factors is to make the cost of shielding gas be 20¢ to 30¢ per hour—about $^1/_{20}$ of the cost of the inert gas requirement.

Under the influence of arc heat it is generally believed that carbon dioxide breaks down into carbon monoxide and oxygen. In the area of the arc itself the gases breakdown further into atomic form. In the area surrounding the arc where the temperature drops to 634° C the carbon monoxide reacts with oxygen to reform carbon dioxide. An arc in carbon dioxide atmosphere is actually shielded by carbon monoxide and oxygen. Neither carbon dioxide or carbon monoxide are soluble in molten metal to any great extent,[1] although the oxygen present due to decomposition is quite soluble in molten metal.

The main drawback to the immediate widespread application of carbon dioxide has been the erratic actions of the arc. Figure 1 shows a print of three strips of high-speed motion picture film exposed at $^1/_{4000}$ of a second per frame. A careful, frame by frame study of these high-speed color moving pictures shows that there is little or no regular droplet formation as is the case with inert gases. Instead, there seems to be a jet action forcing the irregular droplets up; under some conditions, there is also some spatter. In spite of this, however, welds are remarkably uniform.

Initial Development Work

Extensive work in the Welding Development Laboratory of the Ford Motor Co. in Detroit, Mich., under the supervision of John F. Randall and in the General Electric Welding Department in York, Pa., has shown that this erratic arc condition and extensive spatter can be materially reduced to the point where it is practical to use carbon dioxide as the sole shielding medium at tremendous savings.

The way to control spatter using 100% carbon dioxide as a shielding gas is through the use of high current density and short arc length. Many times the arc voltage is specified as the important variable. Actually, arc voltage is a convenient method of measuring arc length but only for a specific current. Holding constant arc voltage does not maintain constant arc length under different current conditions. Constant arc length is the important factor because arc length is a factor that controls bead contour, penetration, porosity, pool agitation, and undercut. The arc voltage, needed to maintain certain bead contour and penetration factors, changes as the current changes, but usually the same arc length will produce the same physical arc characteristics even though the current is changed. Therefore, the variable to control is arc length not arc voltage.

Arc Length Effects

In the consumable electrode gas-shielded process, it has been proved that all known arcs in inert gases have volt-ampere characteristics that rise.[2] And, furthermore, the generator that best matches the volt-ampere curves will produce welds automatically with the same arc length, under different current requirements.

Carbon dioxide is no exception; its volt-ampere curve also rises (Fig. 2). The importance of knowing the volt-ampere curve of carbon dioxide is that with this knowledge the arc length can be accurately controlled. When using carbon dioxide exclusively as a shielding gas in the process, it is necessary to hold a very short arc to reduce the bad effects of spatter and to reduce porosity. When a short arc is employed, the electrode tip operates near or even below the surface of the plate and the majority of electrode droplets, which might produce spatter with a long arc, are deposited in the puddle, and so cause very little spatter.

Figure 2 shows the volt-ampere curve of mild steel welding in carbon dioxide gas. The most optimum welding conditions can be found in the shaded area. Studies of high-speed motion pictures of the arc (Fig. 1) and oscillograms indicate very clearly that the short arc technique causes many momentary short circuits

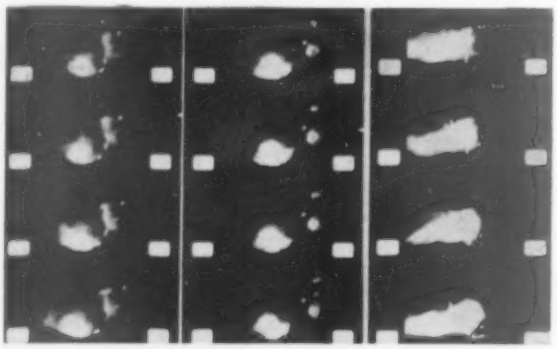

Fig. 1 Consumable electrode welding with $^1/_{16}$-in. steel electrode, CO_2 gas, 4000 frames per second, 300 amp

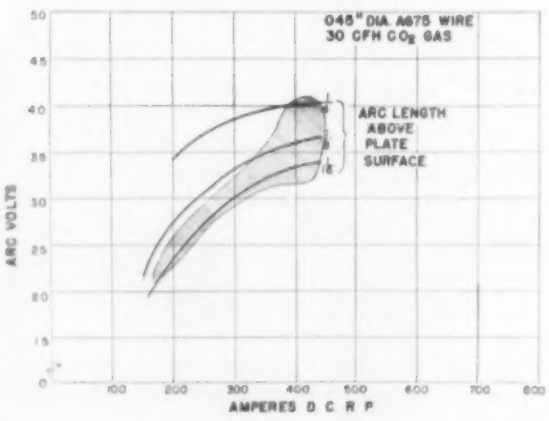

Fig. 2 Volt-ampere curve

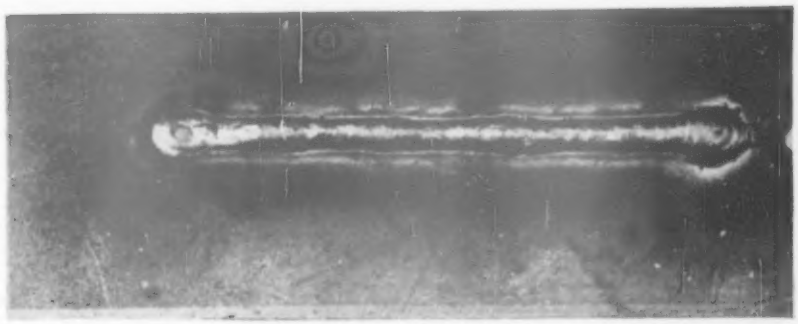

Fig. 3(*a*) Short arc 350 amp-28 arc volts weld bead on semikilled steel, CO_2 gas—30 cfh

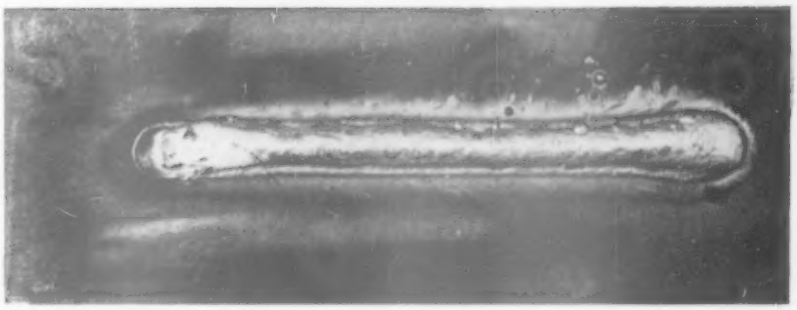

Fig. 3(*b*) Long arc 350 amp-37 arc volts weld bead on semikilled steel, CO_2 gas—30 cfh

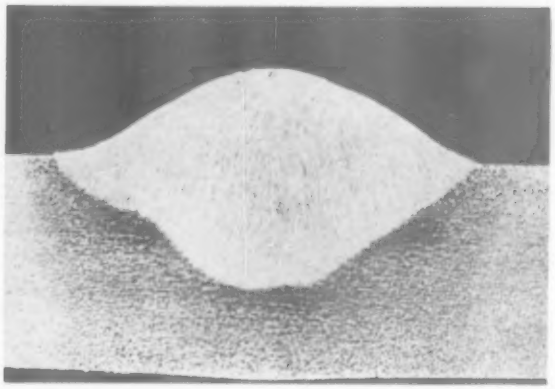

Fig. 4 350 amp-37 arc volts weld bead on semikilled steel, CO_2 gas—30 cfh

of the arc[3] quite similar in nature to that observed when welding with conventional metal arc flux covered electrodes. The melting rate for steel electrodes in carbon dioxide gas is much lower than for argon. This means that for a specific feeding rate the carbon dioxide arc requires a higher current than argon. Stated in a different way, the carbon dioxide shielded arc produces more heat than argon-oxygen because the practical welding current and arc current range is higher. This extra high heat gives an inherently deeply penetrating arc with carbon dioxide gas.

Figure 3 shows the surface of a plate with a long and a short arc, showing the spatter present in the long arc and eliminated in the short arc. Figures 4 and 5 show the bead contour with a long and short arc using the same wire feeding speed and current. The short arc is deeply penetrating while the long arc has a very shallow penetration.

Current Density Effects

The other variable that should be controlled to produce the best welds with carbon dioxide is the current density. It is important to use a very high current density for optimum results, about 100,000 amperes per square inch and approaching 200,000 amperes per square inch. This would be the case with a $^3/_{64}$-in. electrode at 350 amp. At 350 amp, 520 in. a minute of $^3/_{64}$-in. steel wire are consumed per minute, in argon only 280 amp would produce the same burn-off rate.

Figures 4 and 6 show the penetration deeper with the high current than with the low current using the same arc length and electrode feeding rate.

It is possible to hold a long arc and reduce spatter and porosity to an allowable level by using high feeding speed with the resultant high current density. It is a fact in consumable electrode gas-shielded welding that the burn-off rate in inches per minute varies with the current density on the electrode for any given wire and gas.[4] Arc length has little or no effect on changing the current needed to produce this burn-off rate. When using 100% carbon dioxode as a shielding gas the self-regulating action of the arc occurs just as with the more familiar inert gas shields. Current density is the key to the self-regulating action. Because it is so high, burn-off rate is high. Feeding speed must equal burn-off rate; if it does not, the arc will get shorter or longer, and the change in current density will then stabilize at the proper amount to make the burn-off rate match the feeding speed.

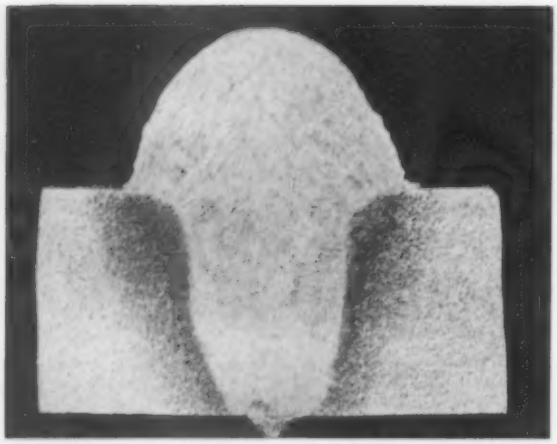

Fig. 5 350 amp-28 arc volts weld bead on semikilled steel, CO_2 gas—30 cfh

Welding Results

Figure 7 shows butt weld, $^1/_4$-in. plate, no joint preparation, using carbon dioxide on semikilled steel, 23 ipm travel speed, wire feed 340 ipm, arc length $^1/_{16}$ in., arc voltage 37 v, arc current 470 amp. Figure 8 is a radiograph of the butt weld shown in Fig. 7. Note the soundness and the lack of porosity. Figure 9 shows a fillet joint, no joint preparation, using carbon dioxide on semikilled steel, 19 ipm travel speed, wire feed 495 ipm arc length $^1/_8$ in., arc voltage 40 v, arc current 620 amp. This joint shows the extremely deep penetrating arc.

The deoxidization technique used in making mild steel has a profound effect on the potential quality of the resultant weld although quantities of surface oxide can offset good deoxidization practice. Some researchers indicate a belief that the use of carbon dioxide prevents the formation of porosity.[4] It seems improbable that carbon monoxide could reduce porosity in the steel by combining with oxides in the metal and forming carbon dioxide thus preventing the oxides from combining with the carbon present, since carbon monoxide is insoluble in molten steel. The oxygen decomposed from carbon dioxide, however, is soluble in steel but it seems as if it could only increase porosity since it could only supply more oxygen for the reaction with carbon. We believe, however, that the main source of porosity is the combination of carbon with oxides already in the base metal—the resultant bubbles of carbon monoxide (even though it is not soluble in the molten metal) tending to become trapped by the freezing metal before it can rise to the surface and escape. A close visual study of the arc in carbon dioxide on rimmed steel shows the gas bubbles rising to the surface and escaping or being caught in the act of escaping and being trapped in the weld.

Higher Quality Welds Possible

We believe the higher current densities employed

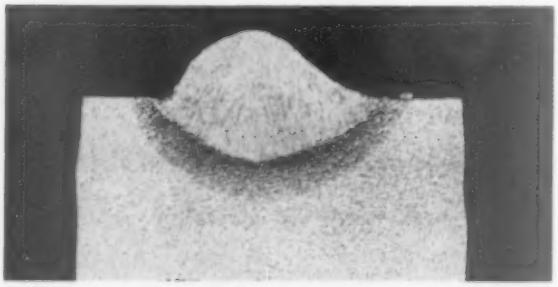

Fig. 6 190 amp-34 arc volts weld bead on semikilled steel, CO_2 gas—30 cfh

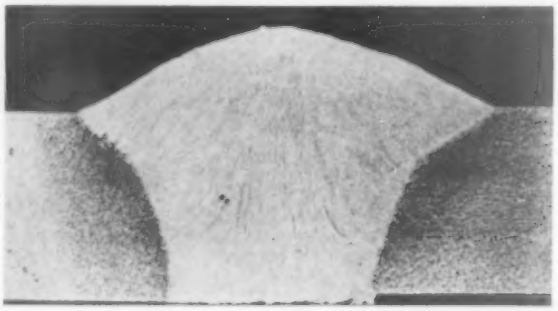

Fig. 7 470 amp-37 arc volts butt weld on semikilled steel with no edge preparation, CO_2 gas—30 cfh

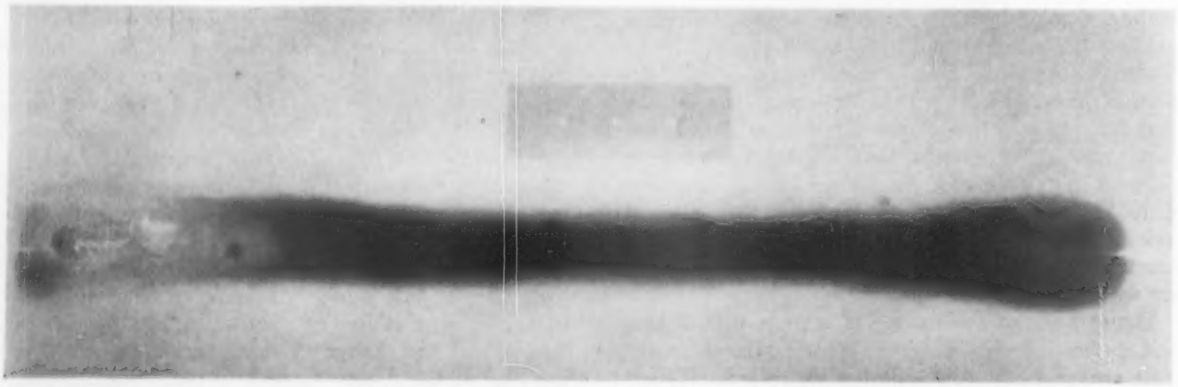

Fig. 8 Radiograph of a butt weld on $^1/_4$-in. semikilled steel; no edge preparation was used for this weld

in carbon dioxide welding, the superheating of the weld metal, the violent agitation of the molten pool all tend to permit more carbon monoxide to escape. It is in this way that the use of carbon dioxide as a shielding gas may be more effective in reducing porosity than inert gases. Figure 10 illustrates the welding arc crater using carbon dioxide gas.

Ventilation Practices

Unlike argon or helium, carbon dioxide, is not an inert gas. Carbon dioxide is toxic and irritates the nose and throat if levels exceed 5000 parts per million. This is about 17 times the amount normally in the air. The effects of carbon monoxide are well known. The eight-hour maximum average atmospheric concentration without injury to health listed in Industrial Hygiene Digest is 100 parts per million.

With this new gas shielding medium, strict adherence to the accepted practices for ventilation of the welding area are necessary.[5] Some portion of the carbon monoxide formed in the arc escapes to the air as free carbon monoxide as is the case when welding with cellulose coated mild steel electrodes. Very recent exploratory welding tests were made in our laboratory at current levels of about 400 amp using carbon dioxide gas and a $^1/_{16}$-in. diam steel electrode. These tests were conducted in a chamber; the results indicated that with 30 cfh of carbon dioxide gas flowing, about $^1/_2$ cfh of free carbon monoxide was liberated. Based on these tests, in order to keep below the established concentration limit of carbon monoxide and carbon dioxide when welding on a continuous basis, if the welding area were 20 x 20 x $12^1/_2$ = (5000 cu ft) air would have to be changed at a rate of 100 cfm. This compares to that recommended by the American Standard Assn. Publication Z49.1-1950 of 2000 cfm.

Further tests indicate that an E6010 $^1/_4$-in. diam electrode, at the same current, produced only about one-tenth of the volume of carbon monoxide while producing at least twice as much smoke as the carbon-dioxide shielded arc. The tests with an arc shielded with carbon dioxide indicated that most of the carbon monoxide liberated was present in the smoke fume since no perceptible amounts of carbon monoxide could be measured outside the fume area. For this reason the operator should not be located so that smoke and hot gas rising from the arc impinge on his face. The ultraviolet light from gas-shielded arcs may generate large amounts of ozone and in some applications require ventilation in excess of that recommended by American Standard Assn. Publication Z49.1-1950 to control concentration of this gas.

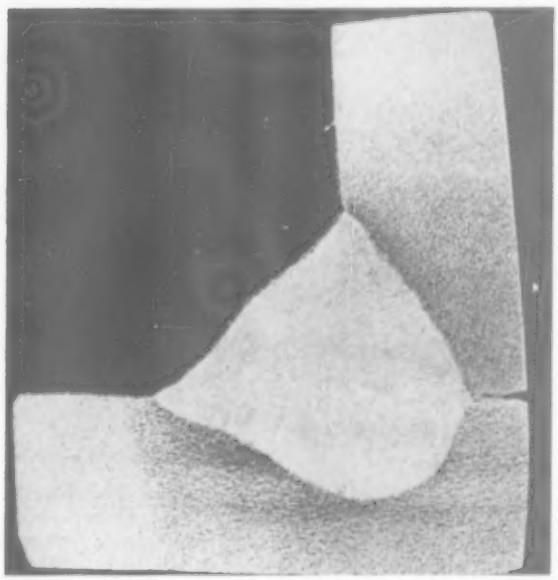

Fig. 9 620 amp-40 arc volts fillet weld on semikilled steel, CO_2 gas—30 cfh

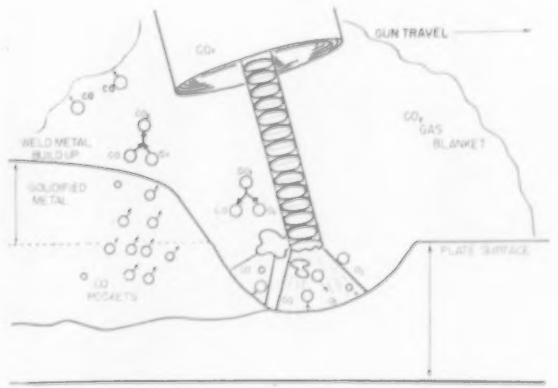

Fig. 10 Consumable electrode welding with CO_2 gas on mild steel

Summary

Since very high currents, deeply penetrating arcs and fast travel speeds are needed with carbon dioxide welding, an automatic travel mechanism is desirable. Work with carbon dioxide can be done manually but fast travel speeds are required. In the operation of hand welding, however, a stable welding generator is necessary to permit the arc length to be held to that value necessary for good welds.

Completely porosity-free welds on the poorest grade rimmed steel are not yet possible since technique, knowledge and available electrodes are not sufficiently advanced at this time. However, many applications of gas-shielded welding on semikilled steels may be possible right now with a use of carbon dioxide gas and the correct welding techniques, resulting in great savings compared to using inert gas.

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AIR REDUCTION'S NEW LIQUID OXYGEN PLANT

The newest liquid oxygen plant built by the Air Reduction Sales Co. in Riverton, N. J., typifies an industrial trend toward large capacity oxygen-producing plants.

The main production building at Riverton houses two producing columns, each capable of turning out 55 tons of liquid oxygen a day—a total daily capacity of 110 tons—and a monthly capacity of about 75 million cubic feet. Full-scale production at Riverton coincides with the closing down of Airco's first and oldest oxygen plant at Germantown and Allegheny Aves. in Philadelphia. Back in 1916 "Philadelphia Number One" was a big, pioneer plant in a brand new industry and it produced each day about 4 tons of oxygen. In the summer of 1954, after 38 years of solid performance, "Old Number One" closed its doors for the last time. The modern Riverton plant has a daily production of more than 25 times that of the Philadelphia plant.

Each producing column at Riverton has a control panel which consists of automatic controls and analysis equipment. In addition to automatic operation provided with this equipment, the operator can also tell temperatures, pressures, flows and analysis of the various gases throughout the entire manufacturing process. An audible signal system notifies the operator the moment any phase of the operation is off control.

With a complete array of distribution equipment—special trailers, tank trucks, railroad tank cars—Riverton serves steelmaking, metalworking and chemical industries primarily in the flourishing Delaware River Basin. Large quantities of gases also are transported economically in the liquid state to more distant

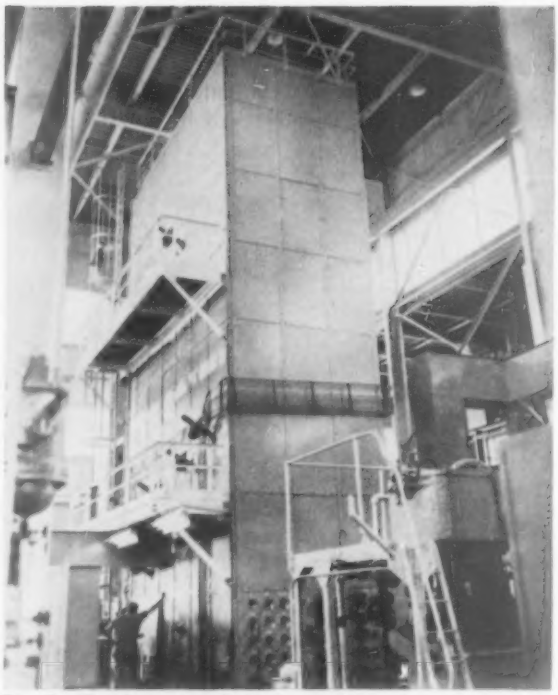

Fig. 2 The four-story high separation column at Riverton. Gases are "tapped off" at varying conditions of temperature

Fig. 1 Air Reduction's new liquid oxygen plant at Riverton, N. J.

Fig. 3 One of the control panels at Airco's new liquid oxygen plant, Riverton, N. J.

points. Products include liquid oxygen, nitrogen, argon, and some of the rare gases—neon, krypton and xenon.

The facilities at Riverton also serve as a large distribution point for the Philadelphia-Camden area of every product in Airco's electric arc welding and oxy-acetylene welding and cutting line. Items ranging from welding tips to automatic welding and cutting equipment are stored and sold directly to users and dealers in the area. Oxygen, nitrogen and argon are also sold in gaseous form by converting substantial portions from liquid to gas at the plant. Calcium carbide, from which acetylene gas is made, is stocked in drums and sold to industries which operate acetylene generators. Acetylene gas is also sold in cylinders. Helium is marketed from here.

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IRON-POWDER ELECTRODES BOOST WELDING RATES ON DIESEL COMPONENTS

Fast manual welding performed on exhaust manifolds, oil pans, crankcases and fuel tanks

BY HERBERT CHASE

Fast and highly effective arc welding is done on diesel engine components in the Three Rivers Works of Fairbanks, Morse & Co. Many of the assemblies are 8 ft or more in length and are fabricated from low-carbon steel plate, most of which is flame cut to required shape and some is rolled or otherwise formed.

Many of the welds are quite short and have to be made by hand equipment. A rapidly increasing proportion of all hand welds is now made with iron-powder electrodes, because high speed is attained, welds are of high grade and considerable economies result.

Herbert Chase, ME, is a consultant.

Fig. 1. Using Lincoln Jetweld iron-powder electrode to make plug welds around stud ends where they project through holes in the outer wall of a Diesel engine exhaust manifold

Fig. 2. Fillet welds at inspection port rings of manifolds made with $^1/_8$-in. iron-powder electrodes.

Among assemblies on which many welds are made with the iron-powder electrode are double-walled box section exhaust manifolds produced in several lengths up to 13 ft over all, cooling water being circulated between the walls in service. Walls of 10-gage steel are spaced apart by numerous short studs whose inner ends are joined to the outer face of the inner wall by fillet arc welds. These studs are spaced so that they project into holes pierced in the outer walls, and when the latter are put in place, the outer ends of studs are plug welded with $^1/_8$-in. electrodes to the outer wall as shown in Fig. 1.

Manifold inspection ports are formed by flame-cut rings which, though of generally circular shape, have an irregular contour to provide extra metal around holes for studs. These port rings are joined to inner walls by fillet welds and project through holes in the outer wall where a $^1/_8$-in. iron-powder electrode is used to make fillet welds as shown in Fig. 2. Such welds are made about 25% faster than when conven-

Fig. 3. Welding side rails to the edges of the formed sheet of oil pans

Fig. 4 Plug welds made by hand help to fasten covers of fuel tanks to mating structure

tional electrodes are used. Moreover, these welds, which approximate 8 in. in diameter, require only two electrodes where before it took three electrodes per port. Besides this, the welds are of superior quality and avoid weld spatter so that the cleaning formerly required is not needed. These welds, made with iron-powder electrodes, are considered equal in quality to submerged arc welds.

Other welds are made along both sides of $^3/_4$ x $^3/_4$-in. rails of oil pans as shown in Fig. 3, joining these rails to $^3/_{16}$-in. steel plate formed to half cylindrical shape. About 60% of the welds made in fabricating crankcases are also made with $^3/_{16}$-in. iron-powder electrodes. Fuel tanks for diesel applications are fabricated from steel plate components, chiefly by hand welding with conventional electrode. Covers for such tanks are pierced with holes measuring about $1^1/_2$ x 7 in. left for plug welding the cover to mating interior reinforcements. Welding is shown in Fig. 4.

The same advantages are gained here as in the manifold welds, the savings in electrode and time and the ease with which uniformly high quality is attained being valued especially. Comparative freedom from spatter and the ease with which any spatter is removed effect further savings.

SOME HINTS FOR THE AUTO SHOP

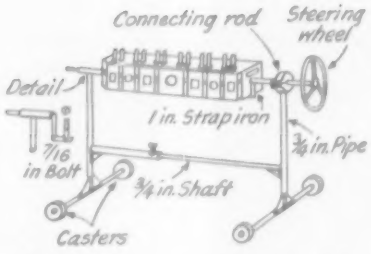
BY A. MACLEOD

Removing Bearing Cups

To remove a bearing cup from a wheel without destroying both, heat a narrow strip across the bearing cup with a torch. When the heated portion of the cup turns red, cool it off with water. This will cause the metal to shrink, and the cup will be loose enough to work out. In some cases, the cup may even fall right out.

Cylinder Head Stand

This is a cylinder head stand which can be made from scrap metal and parts found around any auto shop. It can be adjusted to take any size head up to the largest of tractor heads, by slipping the shaft through the collar made from an old connecting rod. Once the cylinder head is tightened in position, it can be rotated to any convenient work angle by means of the steering wheel and held there by tightening the thumbscrew.



The casters on the frame make this stand portable.

Welding Fenders

When gas welding fenders, it is best to use a $^1/_{16}$-in. welding rod. This permits the use of a small tip on the torch and the heat does not spread and cause the fender to warp. A small tip also avoids overheating the metal.

Welding Car Bumpers

Try braze welding automobile bumpers when they need repair. They are made of high-carbon steel and it is difficult to fusion weld them. Build up the bronze metal on one side to a thickness of about $^1/_8$ in. Braze weld and reinforce a strip about $^3/_{16}$ to $^1/_4$ in. thick to the other side.

A. MacLeod is associated with Linde Air Products Co., New England District.

DOING IT BETTER

BY WILLIAM BROTHERTON

Through constantly improved methods, the Ryan Aeronautical Co. of San Diego, Calif., is saving time, space and material in production. These savings are accomplished through a coordinated program

William Brotherton is associated with Ryan Aeronautical Co., San Diego, Calif.

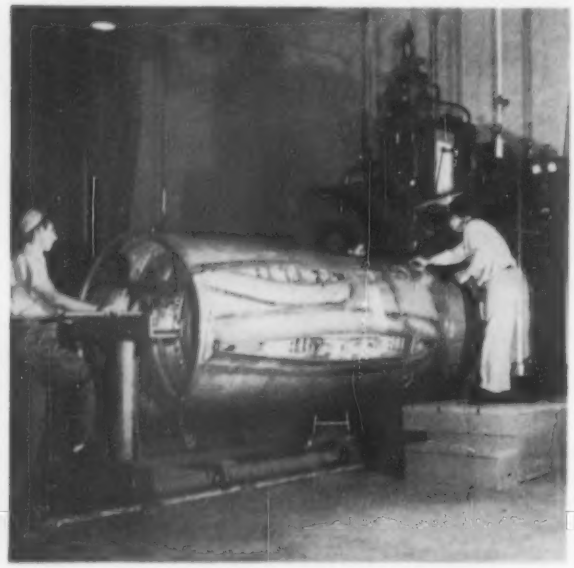


Fig. 1 Old way...Two men needed to seam weld large fuel tank. Operator (*right*) signaled helper to move tank right or left to keep seam weld straight and prevent spiraling weld seam

Fig. 2 New way...One man does the job. He controls tank alignment with valve temporarily located on seat. This actuates air cylinder mounted on rear of fixture to yaw tank. Even sharply tapered tank sections are smoothly seam welded with this simple control system

Fig. 3 Old way...Inner combustion chamber for jet engines is spot welded with individual spot welds on standard machine. Previously, shell, cap and exit body had to be aligned in a fixture and spot welded together. System required two employees and involved many operations

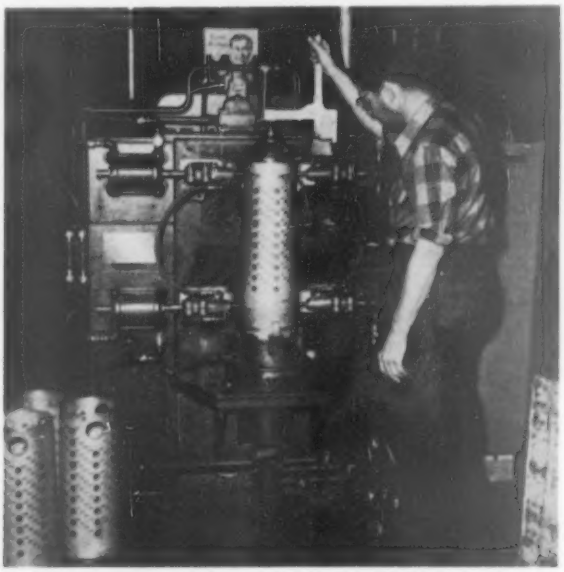


Fig. 4 New way...Special machine aligns and spot welds inner combustion chamber assembly, making four spot welds at once. Perfect alignment is achieved by expanding inner arbor. Part is rotated to make 32 spot welds. Operator is relieved from tiring, precise work

carried on by the Methods Engineering, Production Engineering and Production departments.

The methods engineers are charged with developing production layouts, recommending new machines and improving methods. They stimulate the flow of new ideas from employees and assist in putting them into effect. The production engineers work closely with methods engineers, and develop the tools and fixtures used to produce every product. The production employees, being closest to the scene of action, are the most lucrative source of suggestions on how the work may be improved.

Some typical examples of the improvements brought about through the close cooperation of these groups with regard to the production of welded parts are illustrated in Figs. 1 through 8.

Fig. 5 Old way...Manual method or arc welding stainless steel nipples for exhaust systems took 3 min with foot-controlled rotating device, plus finishing time

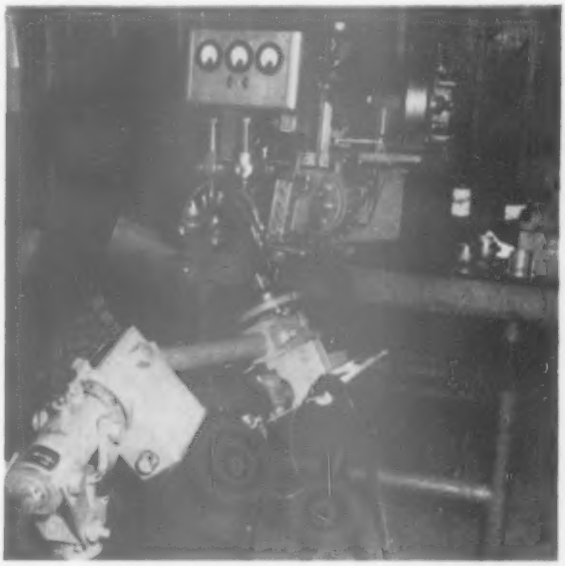


Fig. 6 New way...Fast consumable electrode inert-gas-shielded arc-welding method and special positioner produces a better part in just 7 sec. New method eliminates machining and saves manufacturer approximately $6000 a month in cost

Fig. 7 Old way...Operator held and aligned outer combustion chamber for jet engines while spot welding, making one spot weld at a time. Job required skill to hold parts round. Handling tired operator

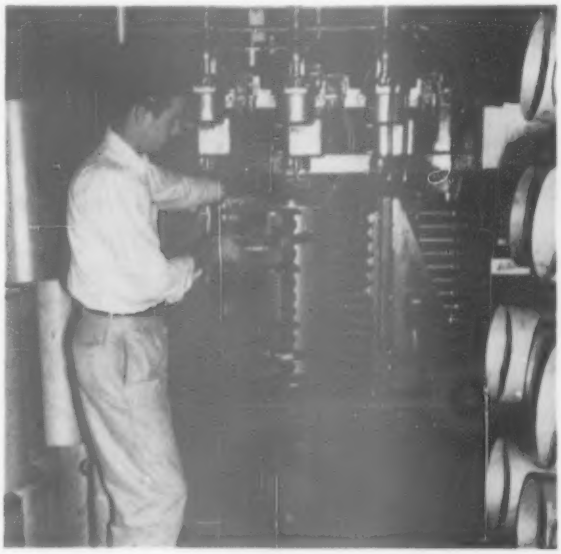


Fig. 8 New way...Welding machine makes 12 spot welds at once with hydraulically operated electrodes. Expanding arbor keeps parts round and reduces rejects by 70%. Eliminating hold reduces fatigue. Parts are kept uniform

Society News

Welding Show to Be Staged in Kansas City

Continuing to test new frontiers for the spread of the science of welding, the AMERICAN WELDING SOCIETY will hold its next Spring Technical Meeting and the Welding Show at Kansas City, Mo., from June 7th to 10th, inclusive. The show will be open during the last three days.

The Welding Show, which displays and demonstrates, under simulated factory conditions, the largest assemblage of welding equipment and accessories to be found anywhere in the world, is now in its third year.

In previous years, it was held in Houston, Tex., and in Buffalo, N. Y. The decision to take the show to Kansas City was made on the basis of the fact that the Mid-Continent is not only a new area in itself but is only one day's travel from most industrial centers in the country. The expanding industrial areas of the South, the Southwest and the West will profit considerably by an exposition and technical conference in the Mid-Continent.

Kansas City's huge Municipal Auditorium will be the site of the exposition. Tentative plans also call for a number of special papers to be delivered in the auditorium, but the technical papers sessions will be held at the nearby Muehlebach Hotel.

Present indications point to the fact that the attendance will be the most impressive obtained for any welding exposition thus far. Manufacturers of equipment and accessories are exhibiting considerable enthusiasm for the show, as indicated by the sales of booth spaces.

Prior to the first public announcement of the show, the exhibit space purchased exceeded the total at the 1954 show in Buffalo. More than 95 per cent of the available space in the Kansas City auditorium already has been purchased and there is a likelihood that it may be necessary to redesign the floor plans to permit additional exhibitors to participate.

Sections are being advised by the Society's headquarters to urge members who plan to attend to make early requests for hotel space. Although civic authorities have given assurances of an ample supply of rooms, hotels convenient to the sessions and the show are limited and they will be assigned on a first-come, first-served basis.

Admission to the show will be free and factory supervisors are being urged to bring groups of younger men to the show to see recent developments in welding equipment and products.

REMINDER

TO AUTHORS

FOR 1955 AWS

NATIONAL FALL MEETING

Authors who plan to propose papers for the 1955 AWS National Fall Meeting in Philadelphia are reminded to forward their abstracts to National Headquarters before the March 15th deadline to assure full consideration. If needed, additional copies of the Abstract Form may be obtained by writing to National Secretary Joseph G. Magrath, American Welding Society, 33 West 39th Street, New York 18, New York.

New Council to Coordinate Technical Activities of the American Welding Society

The AMERICAN WELDING SOCIETY has announced the formation of a Technical Council to plan, review and coordinate all the varied technical activities of the SOCIETY. Establishment of this Council, will further increase the AMERICAN WELDING SOCIETY's services to its members and to the welding and allied industries.

The new Technical Council is composed of leading authorities in the welding industry. The chairman is I. Morrison of Morrison Steel Products, Inc. Members of the Council are: R. W. Clark, General Electric Co.; G. O. Hoglund, Aluminum Company of America; J. H. Humberstone, Air Reduction Sales Co., Inc., president of the SOCIETY; F. L. Plummer, Hammond Iron Works, junior past-president of the SOCIETY; J. G. Magrath, secretary of the SOCIETY, *ex officio;* and S. A. Greenberg, technical secretary of the SOCIETY, as secretary for the Council.

It is expected that forming the new Technical Council will assist in planning and expediting the growing number of technical activities and services sponsored by the AMERICAN WELDING SOCIETY.

In recent years the tremendous growth in activities has required the formation of many new committees, subcommittees and task groups. Increased demands for authoritative welding data and information by industry and code writing bodies has multiplied the work and output of the SOCIETY's more than 100 technical committees and subcommittes. In the past ten years a few of their accomplishments have been the writing of ten new filler metal specifications, a building code for structural welding and the preparation of a comprehensive brazing manual. Work is already started on a similar manual for soldering.

To provide another outlet for the great increase in technical papers, a second National Meeting was started two years ago. At the same time the new National Welding Exposition was organized to operate in conjunction with this National Spring Meeting.

Aircraft and Rocketry Session Sponsored by AWS at Western Metal Congress

An all-day session on aircraft and rocketry has been included by the AMERICAN WELDING SOCIETY in its four days of technical sessions, which constitute an important part of the approaching Ninth Western Metal Congress.

The Congress will be held March 28th–April 1st in the Los Angeles Ambassador Hotel simultaneously with the Ninth Western Metal Exposition in Pan-Pacific Auditorium, largest exhibit structure in the western states.

Both Exposition and Congress will be presented by American Society for Metals, with cooperation of AWS and 19 other technical societies.

S. R. Lanier, chief engineer, Southwest Welding and Manufacturing Co., Alhambra, Calif., and chairman of the AWS Los Angeles Section, has appointed Hugo W. Hiemke, of California Alloy Products Co., Los Angeles, to serve as program chairman for AWS Congress activities.

Mr. Hiemke, in turn, has named Richard C. Hayes, process materials engineer, Douglas Aircraft Co., Long Beach, Calif., as chairman of the aircraft—rocketry sessions. Mr. Hayes has Harlan L. Meredith, research welding engineer, North American Aviation, Inc., Downey, Calif., as his chief aide.

H. W. Hiemke

Others on Mr. Hiemke's general program committee are R. A. Hay, engineering service representative, Linde Air Products Co., and Francis V. McGinley, sales manager and assistant Southern California manager of Victor Equipment Co.

Mr. Hayes and Mr. Meredith announce the following papers will be delivered by the WELDING SOCIETY's Aircraft and Rocketry Panel:

"Fusion Weldability of 24ST Aluminum Alloy"—John Bradford Arthur, research welding engineer, North American Aviation Inc., Downey, Calif.

"Silver Alloy Brazing of Electrical Connections"—Leon Shafin, brazing engineer, Gilfillan Radio Co., Los Angeles.

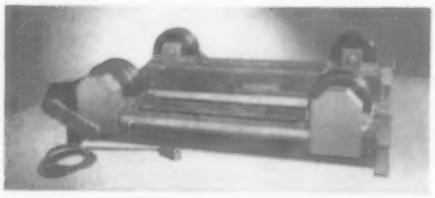
"Resistance Welding of Airframe Structures"—Dennis Samuelson, welding engineer, Solar Aircraft Co., San Diego, Calif.

"Titanium Alloy Fusion Weldability and Correlated Weld Metallurgy"—Charles W. Handova, metallurgist, and Harlan L. Meredith, research welding engineer, both of North American Aviation, Inc., Downey, Calif.

Richard C. Hayes

Aronson QUALITY POSITIONING EQUIPMENT

for Automatic Welding or for Manual Welding



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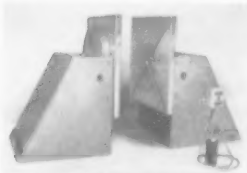

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The Inquiring Weldor

BY JOHN WILSON

Question: What advantages have you obtained by standardizing on "Low Amp" EutecTrodes in your maintenance welding?

Richard Marshall, Detroit, Mich. My company makes thermostatic bimetal products and I frequently have to weld very high alloy steels. I find that Low Amp EutecTrodes make welding easier and faster. Here's one example. Before rolling our bimetal strips to the desired dimensions we run them through a furnace. The flanges that hold the muffle to the furnace on one end and the water jacket on the other were continually breaking off. To make the repair we'd have to wait until the furnace cooled, dismantle, repair and then reassemble. Using ChamferTrode and EutecTrode 680 I make the weld in position and the weld lasts as long as the muffle itself.

Question: How has your work in the forging shop been simplified with "Low Amp" EutecTrodes?

Roy L. Brandon, Dearborn, Mich. The cutting edges on chrome moly steel forging dies used to forge connecting rods have to be rebuilt very often. We've had very good results using EutecTrode #680. The welded dies last as long or even longer than new dies. A second troublesome job is the piston rod of a 4,000 pound air hammer which breaks quite often. Normally a new rod would have to be installed, or, the broken rod removed and sent to a special welding shop for repair. We do the job ourselves and have been getting very good results.

Question: Has Eutectic helped you save time in your repair work?

William Gomez, Providence R. I. It certainly has. Here's an example. We recently had to remove the ⅜ x 15" sleeve inserts at the ends of the 4" thick main shaft of a huge cement mixing and laying machine. On one end, we used a hammer and chisel and it took about 3½ hours of hard work to do the job. On the other end, I used ChamferTrode and removed the insert in about 7 minutes. I used a D.C. machine, straight polarity and about 250 amps. The insert was removed clean as a whistle without damage to the shaft. What a wonderful saving in time, money and hard work.

Question: What has been your experience in working on refrigerated trucks?

Reginald Rorer, West Haven, Conn. I had one job that was real tough. The aluminum racks on the inside of a refrigerated truck had worked loose and had to be repaired. The tracks on the floor of the truck also needed repair. I tried half a dozen different aluminum welding rods but they either wouldn't bond or gave too much spatter. I tried EutecTrode #2101 and got a perfect job. The slightest warping would have ruined the job, but with EutecTrode #2101 there was no warping, no spatter and it made an excellent bond.

EUTECTIC
EUTECTIC LOW TEMPERATURE WELDING ALLOYS clear up welding headaches . . . minimize warping, distortion, stresses and embrittlement. For time and money saving help on welding steels, aluminum, cast iron . . . and all "problem" alloys at temperatures below base metal melting points . . . and for stronger, safer production and maintenance welding just write "Welding Data Bank" for your free copy of "1954 Welding Data File" on your jobs.
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EUTECTIC WELDING ALLOYS CORP.

H. L. Meredith

"New Full Automatic Weld Tooling for Aircraft and Missile Joinery"—Byron Russell, owner-operator, Airline Welding Co., Hawthorne, Calif.

"Metallurgical Aspects of Silver Brazing Titanium to Titanium"—N. A. Tiner, metallurgist, North American Aviation, Inc., Downey, Calif.

With the WELDING SOCIETY'S Congress sessions held mornings and afternoons only, those in attendance will have opportunity to visit the Ninth Western Metal Exposition in Pan-Pacific Auditorium on evenings and the final Friday (April 1st) of the show's run.

Among other valuable features the Exposition will contain scores of new welding developments and many production features evolved in the last year by the aircraft industry.

It will cover 150,000 sq ft, all on the same floor level. Admission will be by registration, free to members of American Society for Metals, AMERICAN WELDING SOCIETY, Society for Nondestructive Testing, American Foundrymen's Society, all of which will hold sessions as parts of the Congress, and 17 other technical groups. Exhibitors also will issue invitations for plant operators and engineers to attend.

No formalities of any kind will be required to enter any session of the Congress at the Ambassador.

American Representatives on Commissions of IIW Selected

Several years ago the Welding Societies of the Free World joined together and formed the International Institute of Welding. Membership in the Institute was an invitation affair and was limited to those organizations which could be classified as welding engineering societies and welding research organizations.

The United States was invited to join, with the AMERICAN WELDING SOCIETY, the Welding Research Council and the Ship Structure Committee accepting membership on behalf of this country.

The IIW accomplishes its main purposes through a group of Commissions. In the United States these Commissions would be called committees. Each country is allowed to name only one representative on the Commissions, although these representatives may be accompanied by any number of experts that seem desirable. Each country, however, has only one vote.

After a period of several years of trial and error, the Institute found it necessary to modify their setup of Commissions, combining some and creating new ones from Subcommissions. The latest list of Commissions and the American representatives on these groups are as follows:

Commission I. Gas Welding and Allied Processes—Herman Ullmer, assistant manager, Development and Engineering Service, Linde Air Products Co., 30 E. 42nd St., New York 17, N. Y.

W. Spraragen, Secretary of American Council, IIW, and Howard Biers, President of IIW

Commission II. Arc Welding—John J. Chyle, director of welding research, A. O. Smith Corp., Milwaukee 1, Wis.

Commission III. Resistance Welding—T. Embury Jones, president, Precision Welder and Machine Co., Cincinnati 10, Ohio.

Commission IV. Documentation—(No representative appointed.)

Commission V. Testing, Measurement and Control of Welds—A. Gobus, director, North American Philips Co., Inc., 750 S. Fulton Ave., Mt. Vernon, N. Y.

Commission VI. Terminology—M. A. Cordovi, chief metallurgist, Babcock & Wilcox Co., Atomic Energy

Division, 161 E. 42nd St., New York 17, N. Y.

Commission VII. Standardization—A. N. Kugler, chief welding engineer, Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Commission VIII. Hygiene and Safety—H. F. Reinhard, secretary, International Acetylene Assn., 30 E. 42nd St., New York 17, N. Y.

Commission IX. Behavior of Metals Subjected to Welding—R. D. Stout, Department of Metallurgical Engineering, Lehigh University, Bethlehem, Pa., and D. P. Brown, senior vice-president, American Bureau of Shipping, 45 Broad St., New York 4, N. Y.

Commission X. Residual Stresses and Stress Relieving—T. McLean Jasper, A. O. Smith Corp., Milwaukee 1, Wis. (W. Spraragen, *Alternate*, director, Welding Research Council, 29 W. 39th St., New York 18, N. Y.)

Commission XI. Pressure Vessels, Boilers and Pipelines—Arthur R. Gatewood, American Bureau of Shipping, 45 Broad St., New York 4, N. Y. (H. C. Boardman, *Alternate*, director of research, Chicago Bridge & Iron Co., 1305 W. 105th St., Chicago, Ill.)

Commission XII. Special Arc-Welding Processes—H. C. Cook, senior process engineer, Technical Development Dept., Air Reduction Sales Co., Murray Hill, N. J.

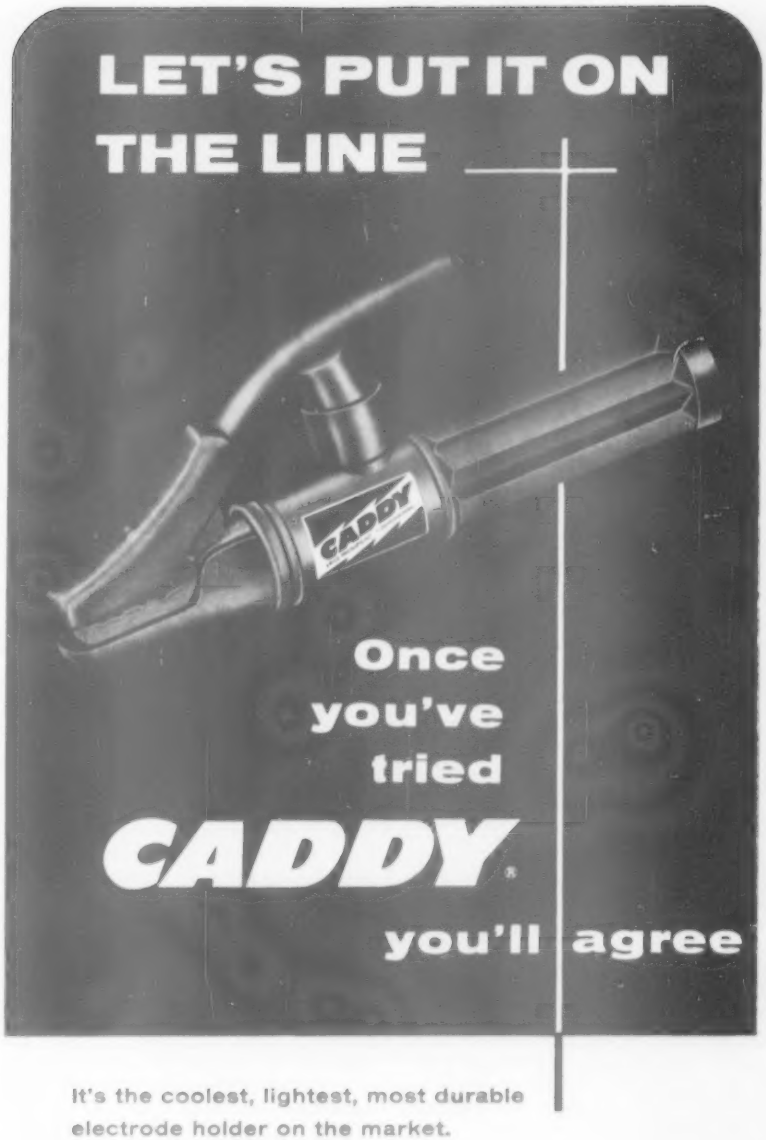
Commission XIII. Fatigue Testing—A. M. Freudenthal, Department of Civil Engineering, Columbia University, New York, N. Y.

Commission XIV. Welding Instruction—Prof. Harry Udin, assistant professor of metallurgy, Massachusetts Institute of Technology, Cambridge 39, Mass.

Commission XV. Fundamentals of Design and Fabrication for Welding—A. Amirikian, Dept. of the Navy, Bureau of Yards and Docks, Washington 25, D. C.

Each year the IIW holds a Congress in a different country. Actually, it accepts the invitation of some specific country which, through its welding society, assures the Central Office of the IIW that the necessary facilities for such a Congress will be available. The 1954 Congress was held in Florence, Italy, May 15th to 22nd. The official record of attendance at this Congress indicated the following representation: Germany 69, Austria 7, Belgium 48, Denmark 21, Spain 7, United States 16, Finland 10, France 52, Great Britain 54, Italy 187, Japan 4, Norway 29, Netherlands 51, Sweden 46, Switzerland 15, Czechoslovakia 1, Turkey 2, Uruguay 1 and Yugoslavia 17—a total of 637.

For the first time, as can be seen from the above, the United States had a sizable delegation. The 1955 Congress will be held in Switzerland, September 11th to 17th.



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The IIW has a general secretary, G. Parsloe, who is also secretary of the British Institute of Welding. In addition, it has a technical secretary, A. Leroy, who is also director of the French Institute of Welding.

It became evident that it would be desirable to have an American group which would occasionally meet to decide upon the action to be taken by the American representatives and delegations. This group was organized informally. It now seems desirable to formalize the existence of such a group and attempts are now under way to give formal standing to this group under the name "American Council of the IIW." Simple rules will be prepared and will be submitted to the AMERICAN WELDING SOCIETY, the Welding Research Council and the Ship Structure Committee for ratification. W. Spraragen, director of the Welding Research Council, has been selected as secretary.

On the Governing Council of the IIW there are three American representatives, namely, Howard Biers, F. L. Plummer and W. Spraragen. For several years Mr. Biers served as one of the vice-chairmen of the IIW and the United States has recently been honored through his selection as president of the IIW.

The American representatives on the various IIW Commissions are selected by the American Council and, among other responsibilities, it will be their job to evaluate the work, objectives and accomplishments of their particular Commission from the American viewpoint.

Any company which desires to take a more active part in the affairs of the IIW, or any engineer or scientist who would like to attend the Congress in Zurich, Switzerland, should communicate with the secretary of the American Council.

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THINGS YOU SHOULD KNOW

During the National Fall Meeting at Chicago, on November 4th both outgoing and incoming Boards of Directors held scheduled meetings. Among the many routine business tasks transacted, were the following of real interest to all AWS Members.

Two new AWS Sections were given official approval to organize as units of AWS; namely the Madison Section with headquarters at Madison, Wis., and the Santa Clara Valley Section with headquarters at San Jose, Calif.

A group in Omaha, Neb., has met with all the By-Law provisions and was given official approval to operate as an AWS Section just as soon as its permanent officers are elected.

Due to prolonged illness G. H. Garrett, director-at-large, from Denver, Colo., tendered his resignation from office. It was regretfully accepted by the Board.

To fill the vacancy created by Mr. Garrett's resignation, the Board, as permitted by the By-Laws, elected James Earthman of Houston, Tex., to serve as director-at-large.

The Board voted to establish the newly created Technical Council as a Special Committee up to May 1955 in order to give it a chance to organize its activities and method of operation. At that time it is planned to recommend that the Technical Council function as a Standing Committee of the SOCIETY.

It was decided to hold the 1955 Spring Convention technical paper sessions, committee meetings, social activities and meeting registration at the Hotel Muehlebach, in Kansas City, Mo., in June, rather than at the Auditorium. While costly to the SOCIETY, it was agreed by all that a more pleasant convention would be made available to AWS Members in a hotel atmosphere.

President Fred L. Plummer, 1952–54, presented his annual report to the Board. It served as his "Address" at the Business Meeting. (*Note:* Full text has been printed in the January WELDING JOURNAL.)

National Secretary Joe Magrath presented his annual report to the Board. It included the reports of the Standing Committees. (NOTE: Members who wish copies may send their written request to National Headquarters.) The Secretary's report was made available at the Annual Business Meeting.

The Board expressed its deep appreciation to President Plummer for his superb leadership during his two terms of office, and presented him with an engraved gavel and block, in a case, as a memento of his chairmanship of the Board of Directors, 1952–54.

The 1954–56 Board under the direction of President J. H. Humberstone, confirmed the election of Roger W. Clark to the office of director-at-large, filling the unexpired term of C. P. Sander who was, in the past national election, elevated from director-at-large to second vice-president.

The Board adopted a ruling in regard to SOCIETY policy on news items and radio broadcasts considered detrimental to welding, as follows: "Headquarters staff, upon receiving information in regard to news items, radio broadcasts, etc., detrimental to welding, shall immediately notify the SOCIETY'S Public Relations Committee, who are authorized to take action deemed to be of best interest to the SOCIETY."

President Humberstone appointed the chairman of the Chicago Section, Amel R. Meyer, to convene a meeting of District Number 7 Executive Committee, with duty to appoint a district director to fill the unexpired term of J. B. Welch who was forced to resign office due to ill health.

It was voted to hold the SOCIETY'S Annual Meeting in 1955, in June, at Kansas City, during the 1955 National Spring Meeting.

The next Board of Directors meeting was scheduled to be held in Birmingham, Ala., on Friday Feb. 3, 1955.

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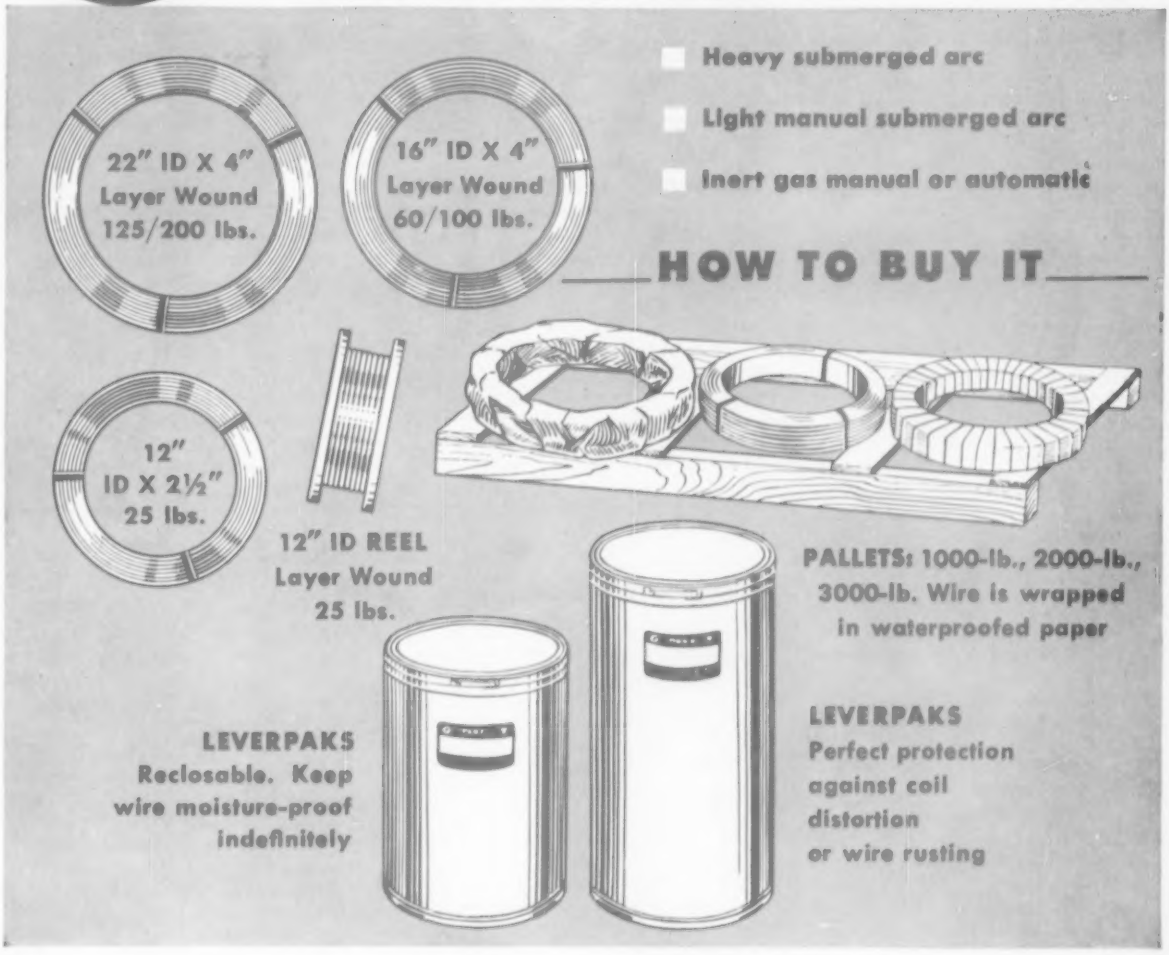

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NEWS of The Industry

Organization Changes Made by Metal & Thermit

Metal & Thermit Corp., New York, announces several changes in its sales organization due to retirements and promotions. These changes, effective Jan. 1, 1955, are as follows:

John B. Tinnon, vice-president and chief sales executive, who has been with Metal & Thermit since 1924, retires but will remain with the organization as a consultant. Mr. Tinnon is a former director and an honorary member of the AMERICAN WELDING SOCIETY.

Donald K. Morgan, formerly with the Kirby Machine Co., and a sales consulting engineer for several years, is promoted to general sales manager. Mr. Morgan has been chief assistant to Mr. Tinnon.

O. L. Howland, formerly manager of sales of the company's welding division, is promoted to assistant to the general sales manager with headquarters in East Chicago, Ind.

Merritt L. Smith, manager of advertising and sales promotion, assumes the additional duties of eastern assistant to the general sales manager, and will continue to make his headquarters at the company's main office in New York.

Robert T. Brown, former Metal & Thermit district manager in Pittsburgh, Pa., is promoted to the position of manager of sales of the welding division, with headquarters in New York.

Kenneth H. Zeigler, sales engineer with the company in the Pittsburgh area since 1951, has been promoted to the post of district manager at Pittsburgh.

•

B. & W. Chief Engineer

George W. Kessler has been appointed chief engineer of the Babcock & Wilcox Co.'s Boiler Division, according to an announcement made recently by W. H. Rowand, vice-president in charge of engineering for the division.

Mr. Kessler, a native of St. Louis, Mo., joined Babcock & Wilcox as an apprentice engineer in 1930 shortly after graduation from the University of Illinois. He gained valuable experience in various departments, including sales, analytical engineering, marine, and proposition, before being named an assistant chief engineer of the division in April 1953.

RWMA Elects Officers

J. C. Wilson, Jr., president of Acro Welder Manufacture Co., Milwaukee, Wis., was elected president of the Resistance Welder Manufacturers Assn. at their Annual Meeting in Detroit recently.

Mr. Wilson served RWMA during the past year as vice-president and has been active in connection with work done by the Association's Technical Committee.

Elected to the vice-presidency of the Association was David V. Uihlein of Banner Manufacturing Co., also located in Milwaukee, Wis.

Mr. Wilson and Mr. Uihlein will assume their offices as of Jan. 1, 1955.

The important technical and research activities of the Resistance Welder Manufacturers Assn. will be under the supervision of J. F. Deffenbaugh, Federal Machine and Welder Co., Warren, Ohio, for the next two years.

Mr. Deffenbaugh has long been active in the work of the Technical Committee. He has served for the past two years as vice-chairman and now succeeds H. V. Beronius, Jr., of the Welding Machines Manufacturing Co., Detroit, Mich., who was committee chairman during 1953 and 1954.

Under Mr. Deffenbaugh's active supervision will be the continued revision of the RWMA Manual, which is now being rewritten and extensively enlarged; the development of additional technical bulletins; revised Standards and Specifications, and several research programs being conducted on behalf of the Association at universities in Ohio and Texas.

Jefferson New Owner and Publisher of Welding Engineer

The McGraw-Hill Publishing Co. has announced that it has ceased the publication of the magazine *Welding Engineer*, and that T. B. Jefferson, editor of the magazine for several years, has become owner and publisher with offices in Chicago. The change went into effect on Jan. 1, 1955.

McGraw-Hill acquired *Welding Engineer* in 1945. Mr. Jefferson, editor of the magazine since 1940, came to McGraw-Hill with the publication and remained as editor. *Welding Engineer* was started in 1916 in Chicago.

Mr. Jefferson, who is organizing his own staff, has appointed Felix T. Tancula, now Chicago editor of the magazine, as executive editor. A number of other members of the present staff will join the new company at the Chicago headquarters, 12 E. Grand Ave.

Before joining *Welding Engineer*, Mr. Jefferson had been in the welding field, primarily with the U. S. Army Engineers, as a civilian employee, in engineering and design capacities.

A native of Kansas, he is a graduate of Kansas University, at Lawrence, in mechanical engineering. He is the author of four books in the welding field and co-author of a mechanical design text.

Good Luck, Ted!

"Ted" Jefferson has long been active in the affairs of the AMERICAN WELDING SOCIETY and his many contributions to the art and science of welding are well known to the industry. We, the Editors of THE WELDING JOURNAL, are joined by our associates at AWS headquarters, in extending to "Ted" our warmest congratulations and our sincerest best wishes in his new role as owner and publisher of the *Welding Engineer*.

The JOURNAL Editors

Welding builds it faster, lighter and safer...

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It swims. It climbs. It fights. It's tough and strong. For, from stem to stern, this L. V. T. is welded.

Welding saves precious weight and countless man-hours in construction. It avoids the rivets and bolts which become as lethal as shell fragments under shock.

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So weld shops, with small operations or large, are finding radiography valuable both for building reputations for good work and for expanding into new fields. If you would like to explore how Radiography can help you increase your business, get in touch with your x-ray dealer. He'll gladly talk it over.

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Tensile Strength, 85,000 psi
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Flows Like Silver Solder
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No. 11 Costs Less Per Job
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Comes Bare and Flux Coated
Sold by 700 All-State Distributors

SEND FOR Complete Application Instructions
ALL-STATE WELDING ALLOYS CO. INC.
WHITE PLAINS, N. Y.

Scott-Foster Headquarters

Scott-Foster Ltd has erected a new building at 1215 Clark Dr. in Vancouver, B. C. The new structure houses 3500 sq ft of office space and 4000 sq ft of warehouse, and is constructed of concrete block. It has offices and display area on the main floor, and warehouse space on the lower. Sales counters are arranged on both floors for the maximum convenience of customers. One of the features of the new building is

the demonstration booth which has been provided in order to facilitate customers, to help in sales training and as a location for tests for visiting out-of-town welders. Modern d-c rectifier or transformer type arc welders and new oxy-acetylene torches are available for working demonstrations. Loading facilities are the best possible with a deck level lowered driveway. Parking space is provided on the company property.

C. A. A. Lind, manager of Scott-Foster, is a member of the Puget Sound Section of the AMERICAN WELDING SOCIETY.

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Canadian Welding Awards

The Awards Committee of the Canadian Welding Society, with the support of Society Chapters and Sustaining Member Companies, have announced their intention of initiating the first Canadian technical paper competition on welding subjects during the 1955 winter season.

The program has been developed to promote the growth of the welding and fabrication industries in Canada, and to publicize and reward individual and company progress in the fields of welding design, manufacture and maintenance.

The competition is open to everyone engaged in the welding or associated industries in Canada and the classification of competition has been designed to offer equal opportunity of monetary reward to all sections of the industry.

Entries in the competition may refer to any of the processes of welding, cutting or brazing utilizing any source of heat.

Complete details of the competition may be obtained by writing to the Awards Committee, Canadian Welding Society, Room 423, 73 Adelaide St. West, Toronto, Ont., Canada.

Newest Submarine

Keel plate of the Navy's newest submarine, the SS576, has been laid at the Groton, Conn., shipyard of the Electric Boat Division of General Dynamics Corp. This new Diesel-powered attack sub is part of the answer to Chief of Naval Operations Admiral Robert B. Carney's recent call for more up-to-date submarines to meet the threat of the growing underseas fleet of Russia. Accompanying picture shows the 45-ft section of keel plate being lowered into place on the building ways.

As yet unnamed, the 576 is an improved version of the famous Tang class, developed since World War II, but she will have greater underwater speed.

•

Stud Welding Supplies

Mobile Welding Supply Co., Inc., has assumed the distributorship of arc-welding studs and stud-welding equipment manufactured by KSM Products, Inc., of Merchantville, N. J. They will carry a complete supply of conventional welding studs and equipment in stock at all times. While they will not be able to fill requests for special studs, they will work closely with the KSM plant to expedite delivery of production requirements of users and prospective users in this territory, it was asserted by Rex Taylor, sales manager of KSM.

The area to be serviced by Mobile Welding Supply Co. includes Mobile, Southern Mississippi and Eastern Louisiana. The ten western counties of Florida will be covered by Pensacola Welding Supply Co., a branch of the company in Pensacola.

KSM also provides the services of a field engineer, Richard Sawyer, who operates out of the KSM Field Office in Birmingham, Ala.

Canadian Trade Fair

A Welding and Metals section will be part of the Canadian International Trade Fair for the first time in 1955. Organized in cooperation with the Canadian Welding Society, the new section will display a wide variety of the equipment and materials used in the welding and metal fabrication industries. The announcement was made by E. A. Gill, President of the Society. The 1955 Trade Fair will be held from May 30th to June 10th in Toronto.

•

California Span Wins Prize

Ten bridges in ten states from a field of 68 entries were selected as the most beautiful steel bridges in the country opened to traffic in 1953, in the American Institute of Steel Construction's 26th Annual Aesthetic Bridge Competition. Stainless steel plaques will go to the three top winners. Honorable Mention Certificates will be awarded to the remaining seven.

The Winners (Class II, for Bridges with Spans under 400 Ft., Costing Over $500,000)

Ninth & Tenth St. Connections, Bayshore Freeway, San Francisco, Calif. Owner, State of California; designer, *Bridge Department, Division of Highways, State of California;* fabricator, Bethlehem Pacific Coast Steel Corp.

This bridge was acclaimed by the jury not only as a winner but as "the most imaginative entry, because it is an honest structural solution to a difficult and complex problem." They added, "there is great harmony in the structure even though both single and double columns are used in the supports. It exemplifies the strength, simplicity and integrity which can be accomplished merely by the use of steel alone." For further details see THE WELDING JOURNAL, July 1954, page 633.

Progressive Names Officers

At a meeting held Nov. 18, 1954, the stockholders of the Progressive Welder Sales Co., named J. F. McRoberts vice-president and general manager.

Mr. McRoberts has a wide variety of industrial experience. A graduate engineer from the University of Detroit, he supplemented his engineering education with five years of special study in business administration.

In 1953 Mr. McRoberts joined Progressive as assistant to the president.

In addition to Mr. McRoberts' appointment, the stockholders named John Johansen, Josephine Johnson, John F. Langs and R. F. O'Heron to the Board of Directors.

Realigning executive responsibilities the Board named John F. Langs, vice-president; Josephine Johnson, secretary; John Johansen, treasurer and assistant secretary; and Robert Barley, general sales manager.

•

Anti-Borax Compound Co. Expands

The Anti-Borax Compound Co. has announced its recent purchase of the Cortland Welding Compound Co. On Nov. 1, 1954, it took over all of the latter company's inventory, formulas, trade marks, etc., and will continue to manufacture their "brand names," such as "Cherry Heat," "Climax" and "Boraxette" forge welding compounds and their "Weld-a-Cast" fluxes in the plant located at 1506 Wall St., Fort Wayne, Ind. Cortland Welding Compounds Co. was claimed to be the oldest forge welding compound manufacturer in the country.

•

Litigation Settled

The litigation between National Cylinder Gas Co. and Arthur A. Bernard and his son, Richard A. Bernard, of the Bernard Welding Equipment Co., involving gas-shielded welding developments, has been settled out of court by amicable agreement, and an order dismissing this litigation was signed by Federal Judge Michael L. Igoe in Chicago on Dec. 8, 1954. This high-speed welding process for common steel has been under study for several years. National Cylinder Gas Co. plans immediately to license others to use the new process and its licenses will be available also through Bernard Welding Equipment Co. The special electrodes required and related equipment, including a new semiautomatic machine developed by Bernard, will be manufactured by the Bernard Co. and will be available from both National Cylinder Gas and Bernard Welding Equipment.

Picture above shows partial view of Essex exhibit and men in attendance. Reading left to right, standing, A. C. "Andy" Axtell, Bob Fredricks, Tom Lenihan (United Wire) Ken Brown, Len Riordan, Jerry Roth (All State Welding Alloys) Leo Gorski and Art Wells.

Essex Exhibit

Essex Welding Equipment Co., 17–19 Tichenor Lane, Newark, N. J., recently displayed their complete welding service facilities and equipment at the Industrial Exposition in New Jersey. They are exclusive distributors for the complete line of Hobart Welding Equipment in New Jersey. At the exposition, the company introduced new and improved developments in welding equipment. One of the outstanding features of the display was the showing of the Hobart "Powromatic" Constant Voltage Generator unit used in conjunction with all types of automatic and semiautomatic welding processes. In addition, the company also had on display their new Hobart Automatic Head. Other new and improved equipment included DC Rectifiers, Industrial Type AC Transformers, the Hobart "Rocket 24," a new high-speed contact type electrode and a complete line of welding accessories. A. C. "Andy" Axtell, president of the company, was in charge of the exhibit.

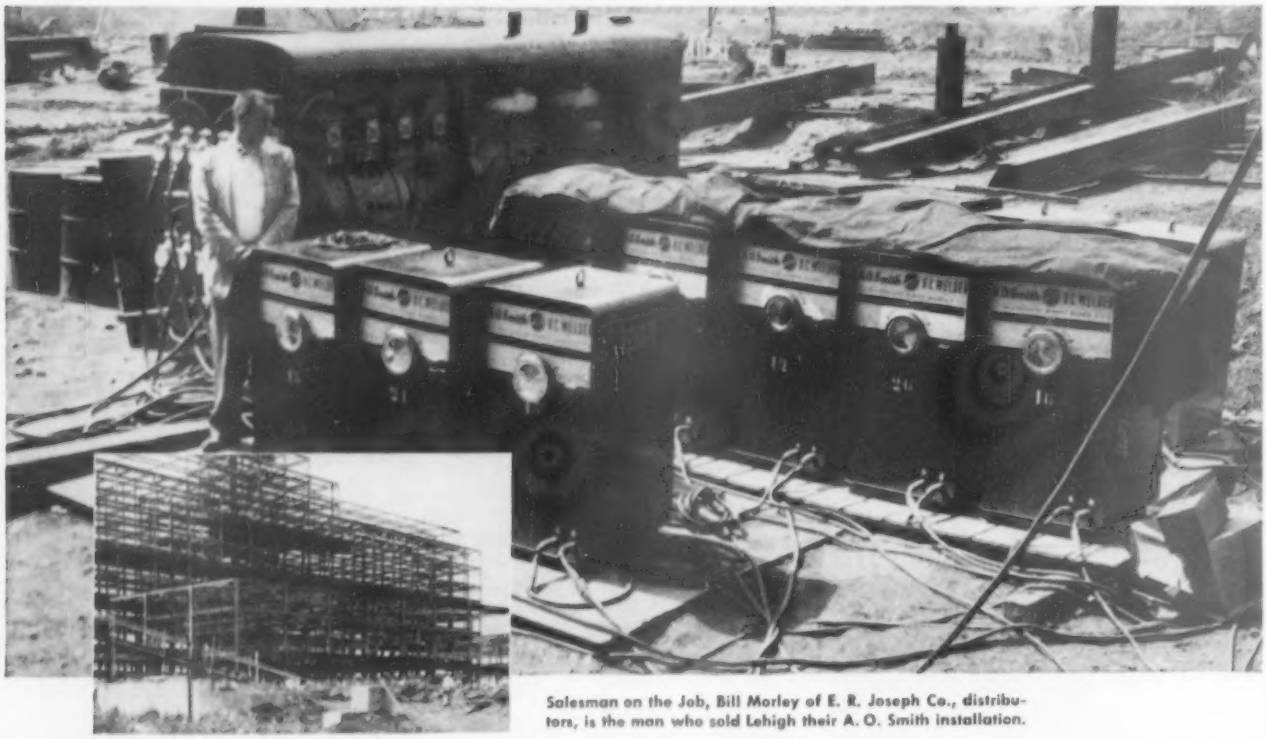
•

KSM Transfers Engineers

Claude Batuk, district engineer for KSM Products, Inc. (Stud Welding Division), has been transferred from the Detroit, Mich., area to the Chicago, Ill., territory. He will work out of the company field office in that city which services Minnesota, Upper Michigan, Wisconsin, Iowa, Northern Illinois and the Lake Michigan area of Indiana. Mr. Batuk is a member of the AMERICAN WELDING SOCIETY.

Donald C. Rolling, another district engineer for KSM Products, has been transferred from the Milwaukee territory to the Detroit area. He will operate out of the KSM Field Office in that city which services the eastern section of Michigan, Western Ohio and most of Indiana.

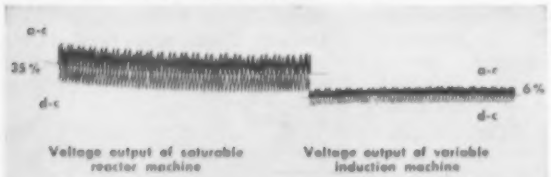
All the advantages of ...yours with A.O.Smith



Salesman on the Job, Bill Morley of E. R. Joseph Co., distributors, is the man who sold Lehigh their A. O. Smith installation.

Proof that only A. O. Smith gives you a d-c rectifier

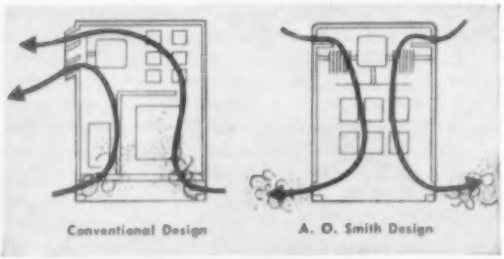
Big voltage "ripple" can keep your welding in rough water!



These oscillograms show why only A. O. Smith variable induction tranformers give you welding characteristics like those of m-g sets. The so-called d-c output of some conventional rectifiers is composed of 35% a-c — compared to only 6% a-c "ripple" in A. O. Smith's output. That's why A. O. Smith gives you a steadier arc . . . smoother welding.

The cards are stacked against you with most rectifier stacks!

Selenium rectifiers last indefinitely if properly cooled. A. O. Smith does it with *preferential cooling*—the air is directed



none of the disadvantages

rotary welding equipment
d-c Rectifier Welders

Lehigh Construction Company selects 10 all-weather A.O.Smith machines for work on large hospital-building job

BACKED by a great record of successful operation, Lehigh Construction Company is widely recognized as one of the East's top contractors. It's only natural that a stand-out performer like Lehigh should select stand-out equipment for its work.

Lehigh recently purchased 10 A. O. Smith heavy-duty d-c rectifier welders. The units are shown at left on a steel erection job for a large, new Philadelphia hospital.

This job in itself illustrates one of the big advantages offered by d-c rectifier welders. Lehigh operates 12 rectifiers off a single 125-kw diesel. With m-g sets on the job, the same diesel will handle only 10 welders — that's two extra welders at no extra power cost.

More good reasons why it pays to operate A. O. Smith heavy-duty d-c rectifier welders

• **LOWER OPERATING COSTS.** These rectifiers cost far less to run than either gas-drive units or m-g sets.

• **LOWER MAINTENANCE COSTS.** A. O. Smith rectifiers are far simpler, much easier to service. No trouble with electric motor or gas engine.

• **PORTABILITY.** Gas-driven welders and m-g sets simply cannot equal the compact, lightweight portability of A. O. Smith d-c rectifiers.

welder with superior welding performance built-in

first over the stacks. And that's *all the air* (not just part of it) — in greater quantities and at higher velocities. A. O. Smith uses a full 1/6-hp fan motor, with permanently lubricated ball bearings, and a big 18-in. blade. (Many conventional machines have only a 1/20-hp motor.) What's more, the air is cleaner because it's drawn in at the top of the case —not from ground level. Add all these up—and you see why A. O. Smith *warrants its rectifier stacks for five years.*

Built by welders — for welders

Get all the facts about the complete line of A. O. Smith a-c and d-c welding machines, electrodes and supplies. *They're built by welders — for welders!* Call your nearest distributor or write A. O. Smith Corp., Welding Products Division, Milwaukee 1, Wisconsin.

Through research ...a better way

A.O.Smith
CORPORATION

WELDING PRODUCTS DIVISION
Milwaukee 1, Wisconsin
INTERNATIONAL DIVISION: MILWAUKEE 1, WISCONSIN

DOCKSON REGULATORS ... Built for Better Service!

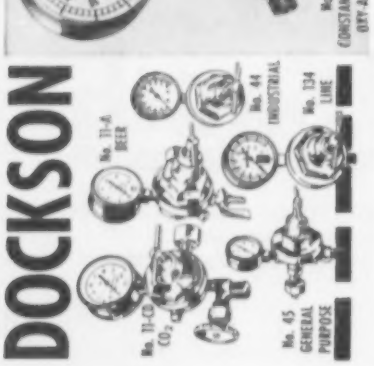
STURDY CONSTRUCTION—Forged brass bodies, shatterproof gauges, dependable safety valves.

LOW COST—Replaceable, self-aligning seats; minimum of moving parts.

YOUR DOCKSON DISTRIBUTOR—a selected specialist stocks a complete line of Dockson Products to give you fast service and personal attention. We back our distributors 100%.

WRITE FOR YOUR DISTRIBUTOR'S NAME AND OUR COMPLETE CATALOG OF WELDING AND CUTTING EQUIPMENT

Dockson CORPORATION 3339 WABASH • DETROIT 8, MICH.



New Headquarters Building

After a number of years with offices in five different buildings, Union Carbide and Carbon Corp. has consolidated its Cleveland offices in a new, modern office building and distributing center at 1300 Lakeside Ave.

The building is located on a plot of land large enough for possible future expansion. Part of it is a one-story office and stockroom, the other part is a two-story office building. It is of steel frame construction with brick masonry walls using Norman-type bricks. Special features provided for the convenience of employees include complete air-conditioning, fluorescent lighting, ample parking facilities and a lunchroom.

The new headquarters houses all the Divisions of Union Carbide now located in the Cleveland Area. These include Bakelite Co., Carbide and Carbon Chemicals Co., Electro Metallurgical Co., Haynes Stellite Co., Linde Air Products Co. and National Carbon Co.

•

Welded Diesel

Worthington Corp. is now building for the U. S. Navy a 2500-kw Diesel generating unit for its Jim Creek Naval Radio-Transmitter Station at Arlington, Wash. It will be the largest single unit yet employed for this class of service. This is one of Worthington's most modern type SW-14 Vee—16-cylinder engines.

This radio transmitter station is the most powerful of its kind in existence and first went on the air last year. The christening ceremonies were given considerable publicity in view of the station's ability to transmit military radio messages to air as well as sea-borne craft, including submarines, anywhere in the world.

The 3000-hp Diesel engine is now being built at Worthington's Buffalo Works. While not the largest Diesel which Worthington has built, this engine will be Worthington's latest type including such special features as high-pressure turbocharging and *welded-steel construction*. Electric Machinery Manufacturing Co. is manufacturing the generator and the switchgear is being supplied by General Electric.

Harnischfeger Appoints Strehler

Harnischfeger Corp. has announced the appointment of C. R. Strehler as sales representative of the P&H Welding Equipment Division for the State of Michigan. Mr. Strehler is well known in the welding industry in and around the Detroit area through his association with Weldit, Inc., of Detroit during the past ten years. Mr. Strehler will have complete charge of all sales of P&H welders, electrodes and positioners in this area. He is a member of the AMERICAN WELDING SOCIETY.

•

Amweld Promotes Minnick

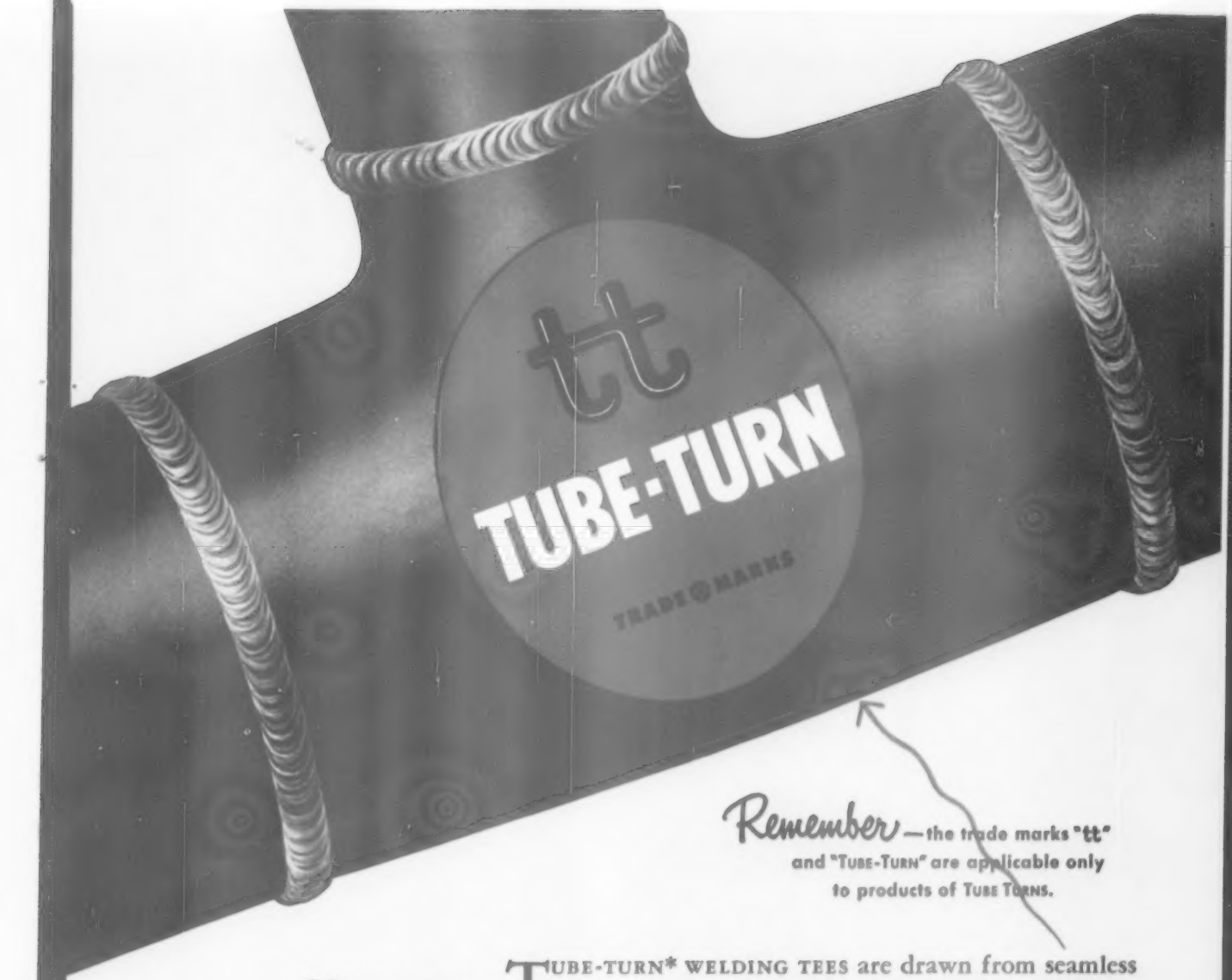
The appointment of M. R. Minnick to the newly created position of vice-president—sales has been announced by W. J. Sampson, Jr., president of the American Welding & Manufacturing Co., Warren, Ohio. Mr. Minnick has been general manager of sales of the company since 1950.

•

Pipe Specification

The ASTM Administrative Committee on Standards this fall accepted recommendations of Committee A-1 on Steel for one new tentative specification.

In response to a request from ASA Sectional Committee B31, Tentative Specifications for Metal-Arc Welded Steel Pipe for High-Pressure Transmission Service (A 381) were developed to fill a definite need. They cover straight-seam double submerged-arc-welded steel pipe 16 in. and larger in outside diameter, with wall thicknesses from $^5/_{16}$ to $1^1/_2$ in., inclusive. The pipe is intended for carrying liquid, gas or vapor, and is suitable for bending, flanging (vanstoning), corrugating and similar operations. The Sectional Committee hopes to refer to these specifications in the next revision of the Code for Pressure Piping.



Remember—the trade marks "tt" and "TUBE-TURN" are applicable only to products of TUBE TURNS.

You get extra strength with *The Leading Brand*

TUBE-TURN* WELDING TEES are drawn from seamless tubing to a barrel shape. This, and other design features produce high strength—averaging over 25% more than required by applicable standards.

Specify TUBE-TURN Welding Fittings and Flanges for extra values: superior products, the exact fitting or flange you need from our complete line, outstanding engineering service. Call your nearby Tube Turns' Distributor. He is at your service!

The Leading Manufacturer of Welding Fittings and Flanges

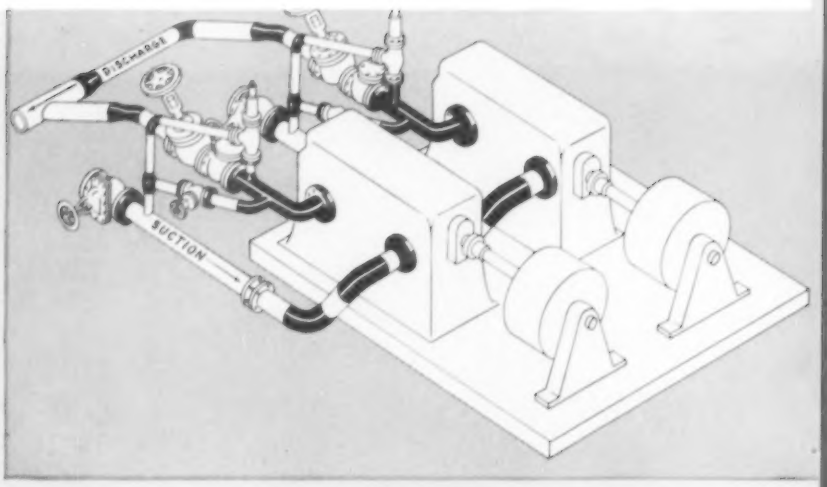
TUBE TURNS LOUISVILLE 1, KENTUCKY

A DIVISION OF NATIONAL CYLINDER GAS COMPANY

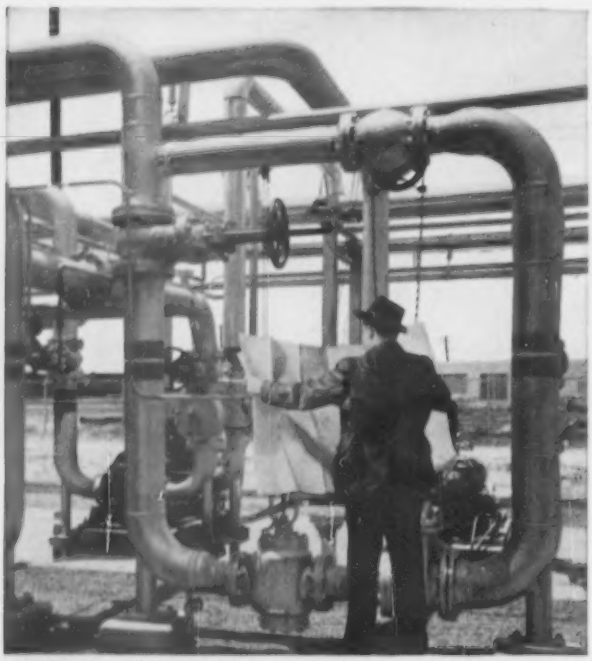
DISTRICT OFFICES: New York • Philadelphia • Cleveland • Toledo • Chicago • Denver • Los Angeles San Francisco • Seattle • Atlanta • Tulsa • Houston • Dallas • Midland, Texas

EXTRA VALUES

Speed up your piping jobs with TUBE TURNS' SERVICE



ENGINEERING SERVICE—Tube Turns' Engineering Service can help you on your piping projects. For example: Diagram above shows an application where TUBE-TURN* Welding Fittings and Flanges simplified the design and erection of pump piping. They save time, save space, and make the piping permanently leakproof and reliable. Ask your Tube Turns' Distributor to give you the pump piping recommendations of Engineering Service.



COMPLETE LINE SERVICE—You can make sure of getting the right fitting for each job when you specify "TUBE-TURN". This is the world's most complete line of welding fittings and flanges, including more than 4000 items, in all piping materials, schedules, and sizes.

AVAILABILITY—Your nearby Tube Turns' Distributor carries local stocks for fast delivery. Call him for good service in good connections.

Technical data service

Tube Turns is recognized as a leading source of authoritative information on piping design. For booklet on "Allowable Working Pressures" fill out and send the coupon now.

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Please send free copy of "Allowable Working Pressures"

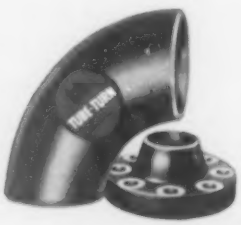
Company Name _____

Company Address _____

City _____ *Zone* _____ *State* _____

Your Name _____

Position _____



DISTRICT OFFICES

New York	San Francisco
Philadelphia	Seattle
Cleveland	Atlanta
Chicago	Tulsa
Denver	Houston
Los Angeles	Dallas
Midland, Texas	

* "TT" and "TUBE-TURN" Reg. U.S. Pat. Off.

TUBE TURNS
A DIVISION OF NATIONAL CYLINDER GAS COMPANY
LOUISVILLE 1, KENTUCKY

PERSONNEL

District Sales Manager

E. F. Hannum has been appointed district sales manager in charge of Ontario operations, for all Manganal Welding Products including the two new ones that have just been released—Flo-Kote AC–DC Welding Electrodes and "Wing-Ding" Individual Slip-Over Tooth Repointers. His headquarters will be in Cleveland, Ohio.

Mr. Hannum has been with the Stulz-Sickles Co. of Newark, N. J., since 1947 covering Ohio and Southern Michigan.

•

Kaufman Promoted

The directors of the McKay Co., manufacturers of commercial and industrial chain, McKay Tire Chains, and McKay Arc Welding Electrodes, announce the appointment of Fred A. Kaufman as vice-president in charge of sales and manufacturing. He will make his headquarters at the Company's executive offices in Pittsburgh.

Prior to his present appointment, Mr. Kaufman was general sales manager of all McKay products. He first became associated with the McKay Co. in 1943 when he joined the McKay Research Fellowship at Mellon Institute on industrial research. Since then Mr. Kaufman has been successively in charge of Technical Service and Quality Control at the York, Pa., plant. He then became sales manager of the Electrode Division of the Company, and in 1950 was made general sales manager. In his new position as vice-president of sales and manufacturing, Mr. Kaufman will be completely responsible for all sales and manufacturing activities of the McKay Co. He is a member of the AMERICAN WELDING SOCIETY.

•

McMillin Relocates

Gordon McMillin, formerly works manager with General Steel Castings Corp. at their plant located in Granite City, Ill., has now joined Canadian Car

and Foundry Co., Ltd., Montreal, Quebec, Canada, as assistant vice-president. He will be in charge of foundry operations at the Longue Pointe Plant. This new position became effective Dec. 1, 1954.

•

Quaas Promoted

Joseph F. Quaas has been appointed to the position of director of manufacturing and production for Eutectic Welding Alloys Corp., Flushing, N. Y. Before his promotion announced by Rene D. Wasserman, president, Mr. Quaas had been manager of the Electrode Production Division.

Before joining Eutectic, Mr. Quaas spent 10 years as a metallurgical observer for one of the nation's large steel companies. His previous work also includes extensive metal quality control and work on electrode coating and another period of years as Research and Development Engineer for one of the largest electrode manufacturers.

Mr. Quaas is a graduate of Newark Tech with an A.E. degree in Chemical Engineering and has a B.S. degree in Industrial Chemistry from Newark College of Engineering. Mr. Quaas is a member of the AMERICAN WELDING SOCIETY and has served on some of its committees.

•

Sales Manager

Robert P. Gehring has been appointed to the position of sales manager with the Cayuga Machine and Fabricating Co. His responsibilities will be the application and sale of the company's Cayuga-matic, automatic welding equipment, and the expansion of their sales

representation on a national basis. He was formerly with the Westinghouse Electric Corp., where he had 14 years of welding sales and engineering experience.

Mr. Gehring has taken active part in AMERICAN WELDING SOCIETY activities in Western New York, and is a past-chairman of the Niagara Frontier Section of AWS.

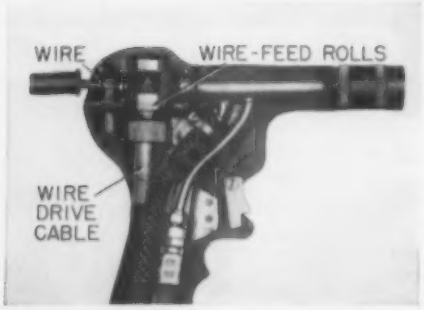
Your Name _____

Position _____

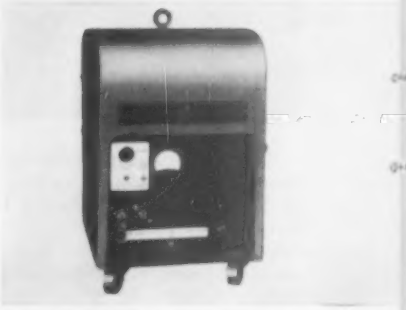
LOUISVILLE 1, KENTUCKY

WELDING ARCS NEWS

WHY G-E FILLERARC EQUIPMENT GIVES YOU MORE APPLICATIONS FOR YOUR INVESTMENT



WIDE RANGE OF WIRE SIZES—.020 to .093—are accommodated by the Fillerarc gun. Gun accepts even smallest diameter wires because it feeds wire by *pulling*—prevents kinking.



HIGH WIRE-FEED SPEEDS—up to 1000 in./mt.—are realized with Fillerarc wire drive—making possible a wide range of applications.

G-E high-speed Fillerarc process solves mild-steel problem at Lukenweld; holds correct arc length automatically, to eliminate burn-back and stubbing

Fillerarc is General Electric's equipment for consumable-electrode, gas-shielded welding. It is semi-automatic and includes a self-regulating generator, a hand gun, and a wire-drive unit which delivers wire-feed speeds up to 1000 inches per minute. Fillerarc equipment has been successfully used on aluminum, aluminum bronze, stainless steel, copper, magnesium, titanium, nickel—and recently—mild steel.

LUKENWELD DIVISION of Lukens Steel, Coatesville, Pa., recently began using Fillerarc equipment to weld mild-steel compressor cases. According to John L. Lang, Welding Engineer for Lukenweld, Fillerarc equipment was chosen over the submerged melt process for two main reasons: easy control of the arc and the absence of flux. (Flux can be damaging to compressor components.) Welds were of sound quality, without undercutting. Compressor cases passed 150-lb pressure tests and snifter tests.

REDUCED BURN-BACK and stubbing are natural benefits of the Fillerarc generator . . . proved at Lukenweld:

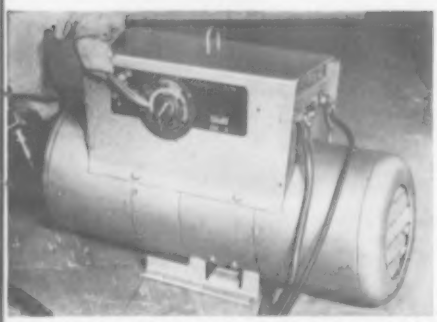
Lukenweld—to meet special production requirements—fixed the Fillerarc hand gun in a mount over a revolving positioner. This positioner held the compressor case. Now, since the gun was fixed, arc length had to remain constant. Otherwise, sudden shortening of the arc could cause stubbing—or a sudden lengthening could cause burn-back to the gun. In either case, time would be lost and the weld damaged.

The Fillerarc generator automatically held the desired arc length—regardless of adjustments in wire-feed speed. Burn-back and stubbing were avoided.

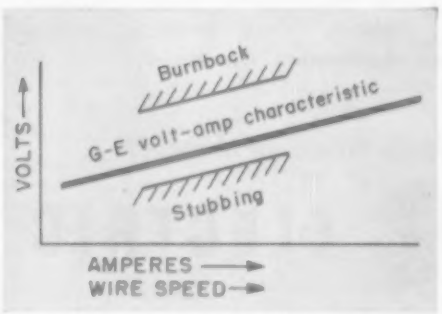
THIS IS PROOF that an operator handling the gun *manually* doesn't have to manipulate it to compensate for arc length or go back to the generator to readjust arc length. He merely sets the voltage and wire-feed speed, and aims the gun. The Fillerarc generator does the rest.

For details on the versatility of G-E Fillerarc equipment, see the story below. General Electric Co., Schenectady, N. Y.

FOR FREE BULLETIN—SEND COUPON ON NEXT PAGE



G-E SELF-REGULATING GENERATOR is the only power source specially designed for this process. Insures proper current for any wire speed.

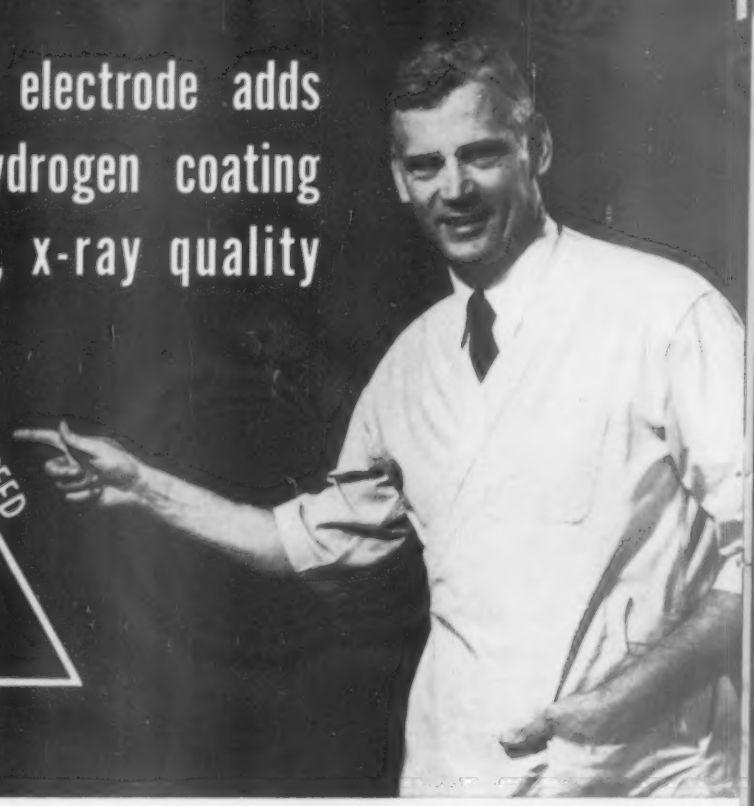


RISING VOLT-AMP CURVE of the exclusive G-E Fillerarc generator matches arc curves . . . does not get into burn-back and stubbing areas. Resulting high weld quality is uniform.

REMOTE CONTROL of wire-feed speed permits the operator to control burn-off rate and current without returning to the generator.

GENERAL ELECTRIC

NEW G-E Strikeasy LH-1 electrode adds metal powder to low-hydrogen coating for speed, ease-of-use, x-ray quality



Consider the payoff qualities you want in an electrode as representing the three sides of a triangle: speed, ease-of-use, and x-ray quality. Frequently, an electrode which is fast and easy to use does not deliver the highest quality—and vice versa. So, the triangle has unequal sides.

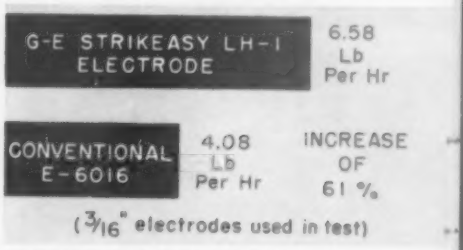
Now, with General Electric's new Strikeasy LH-1 electrode, you get the closest approach yet to the perfect triangle, the perfect electrode. You get the quality you expect from low-hydrogen electrodes plus the speed and ease of use that have given powdered-metal electrodes wide acclaim.

And Strikeasy LH-1 electrode speeds deposition rates up to 61% over conventional E-6016 electrodes—by actual test.

For more information on G-E Strikeasy LH-1 electrode, send the coupon shown below.

Your G-E welding distributor is located near you for fast local service. Ask him about G-E Fillerarc equipment and Strikeasy LH-1 electrode. His name is listed in the yellow pages of your phone book under "Welding Equipment, General Electric."

X-RAY QUALITY is inherent to the low-hydrogen coating. Bad spots in base metal are absent from the weld.



HIGH SPEED of Strikeasy LH-1 is due to metal powder. (Optimum current, ac: Strikeasy, 300 amp; E-6016, 225 amp.)

DRAG TECHNIQUE natural to powdered-metal electrodes speeds deposition, training. Slag is almost self-removing.

Progress Is Our Most Important Product

GENERAL ELECTRIC

Section E710-21, General Electric Co., Schenectady, N. Y.

Please send me the bulletins checked below:

- ☐ GEA-6028 and GER-903—Fillerarc Equipment
- ☐ GED-2483 and GEC-1231—Strikeasy Electrode

NAME.....

TITLE..... COMPANY.....

STREET.....

CITY..... STATE.....

C. P. Sander (left), newly elected president of Woodcraft Rangers, receives gavel from Newton Withers, retiring after two-year term

Sander Heads Woodcraft Rangers

Clarence P. Sander, 2nd vice-president of the AMERICAN WELDING SOCIETY and general superintendent of Consolidated Western Steel Division of United Steel Corp., has been elected president of Woodcraft Rangers, a Southern California organization involving 10,000 boy members and about 2000 senior or supporting members. The Rangers have a budget of about $280,000 a year to provide and improve recreation for these young future citizens.

Mr. Sander succeeds Newton Withers, trade paper publisher as president.

Sales Manager

Progressive Welder Sales Co. has appointed Robert Barley, general sales manager, according to an announcement by J. F. McRoberts, general manager of the company.

Mr. Barley joined Progressive as a product development engineer in 1942 and among his many contributions to the industry was the development of the Condenser Discharge Aluminum Welder.

During the war he served with the Navy as Instructor in Airborne Electronic Equipment.

In 1946, Mr. Barley returned to Progressive and was made national service manager and was promoted to assistant sales manager in 1953. He is a member of the AWS.

EMPLOYMENT SERVICE BULLETIN

Position Vacant

Welding Engineer, B.S. in Electrical or Metallurgical Engineering with three years industrial experience and an interest in arc-welding research. Experience in Inert-Gas-Shielded Arc Welding preferred. Work involves projects in arc welding studies, responsibility for guiding efforts of technicians, planning details of research program and analyzing and reporting data. Salary commensurate with experience and background. Submit complete resume of personal and business history to Personnel Mgr., Air Reduction Research Labs., Murray Hill, N. J.

HERE'S WEST-ING-ARC, newest of all MIG* welding processes

Now—with WEST-ING-ARC—you can weld mild steel up to 30 percent faster than with alternate processes. Using straight polarity for fastest welding speed, WEST-ING-ARC welds without spray, spatter or slag. No need for special surface preparation. Stable, intense arc permits low gas consumption. Welds are smooth, clean, ready to paint without grinding.

Call your Westinghouse office today. Or write for free booklet, *Things You Should Know About WEST-ING-ARC*, Westinghouse Electric Corporation, Welding Division, P. O. Box 868, Pittsburgh 30, Pa. J-21865

YOU CAN BE SURE...IF IT'S Westinghouse

*MIG: metal inert gas

RESEARCH ENGINEERS WANTED

1. A research engineer with chemical background to undertake applied research work on soldering and brazing of aluminum alloys. Several years of industrial experience is desirable. Excellent opportunities are available and the salary is commensurate with ability.

2. A research engineer to undertake applied research work on resistance welding, pressure welding and mechanical joining of aluminum alloys. A good knowledge of electricity, physics and metallurgy is essential. Several years of industrial experience is desirable. Excellent opportunities are available and the salary is commensurate with ability.

All applications should be directed to L. A. Cook, Department of Metallurgical Research, Joining Section, Kaiser Aluminum & Chemical Corporation, Spokane, Washington.

Get the BEST for LESS
Get
"ANTI-BORAX" FLUXES
Fully Guaranteed
SAFE—NON-TOXIC

No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux
No. 4 "Braz-Cast" Flux for bronze welding cast iron
No. 8 "ABC" Sheet Aluminum Flux
No. 16 Silver Solder Paste Flux.

Send for complete Folder

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NOW...
WITH ONE MACHINE
YOU CAN SELECT
the ideal arc
AC or DC
for every job with
LINCOLN
IDEALARC®

4 types of arc at your fingertips

★ AC SOFT ARC

★ AC FORCEFUL ARC

★ DC SOFT ARC

★ DC FORCEFUL ARC

TO THE MAN WHO USES AC

For the first time . . . an AC welder with truly stable arc —*plus* choice of soft arc for smooth, clean welds; forceful arc for maximum in penetration and non-sticking operation.

TO THE MAN WHO USES DC

For the first time . . . a heavy duty, dependable DC welder that combines the efficiency of the rectifier with versatility of selecting a soft and forceful arc. *Then you can switch to AC instantly, where the job can be done better with AC.*

TO THE MAN WHO USES BOTH AC AND DC

For the first time . . . in *one* machine, both AC and DC with selection of soft arc or forceful arc in either AC or DC. Gives you the ultimate in speed, ease, low cost.

START CUTTING COSTS . . . NOW!

Send for Bulletin 1343 showing how hand welding can be simplified, done faster, for lower cost. Write.

GET THE FACTS
SEND FOR BULLETIN 1343

THE LINCOLN ELECTRIC COMPANY

Dept. 1901 • Cleveland 17, Ohio

The World's Largest Manufacturer of Arc Welding Equipment

NEW LITERATURE

Hard-Facing Deposits

"The Effect of Welding Variables on Hard-Facing Deposits" is a reprint of a paper presented before the national meeting of the AMERICAN WELDING SOCIETY by A. Zvanut and V. Peters, development engineers for the Lincoln Electric Co. The paper has been deliberately narrowed in scope to permit full treatment of the two most important procedure variables in hard facing. The importance of deposit analysis and cooling rate in determining the structure of a hard-facing weld deposit are explained in nontechnical, practical language. Test data are presented to indicate areas in which procedure should be controlled in order to create desired performance in a hard-facing deposit. Reprints are available free from the Lincoln Electric Co., Cleveland 17, Ohio.

•

Engineering Irons

Bulletin A-69, is a 28-page basic reference bulletin, compiled primarily for design engineers. It presents the many valuable characteristics of modern nickel cast irons and illustrates their broad acceptance throughout industry. Fifty illustrations indicate wide industrial usage in all sizes and shapes. Twenty-seven useful tables, charts and photomicrographs show how, through the use of nickel alone or in combination with other alloying elements, the engineering properties of cast iron can be controlled to meet service requirements. For your copy, write to International Nickel Co., Inc., New York 5, N. Y.

•

"Welcome" Folder

A new "Welcome To" folder has just been prepared by Sam Tour & Co., Inc., an independent research, development and testing laboratory in New York City. In direct, to-the-point phrases, this new folder answers a number of questions concerning the background and operations of this organization. For your copy write to Sam Tour & Co., Inc., 44 Trinity Place, New York 6, N. Y.

Mr. Tour, president of the company, is a member of the AMERICAN WELDING SOCIETY.

Temperature Indicators

The recent addition of newly developed temperature ratings to the Tempil° Corp.'s line of Tempilaq° temperature indicating coatings has necessitated a revision of their "Instructions for Using Tempilaq°" which is issued from time to time.

The revised version is now available and may be obtained by writing to Tempil° Corp., 132 W. 22nd St., New York 11, N. Y.

Readers who request copies of the Tempilaq° Instruction Sheet will also receive a $\frac{1}{2}$-oz sample of Tempilaq° 300° F to illustrate its function.

•

Electrode Color Markings

The National Electrical Manufacturers Assn. announces the availability of NEMA Color Markings for Electrode Identification, Publication No. EW2-1954. This new book, dated November 1954, supersedes the May 1954 issue. For additional information write to NEMA headquarters at 155 E. 44th St., New York 17, N. Y.

•

Electrode Holder

The Duro Engineering Co. has recently released their new catalog on electrode holders. Copy may be obtained by writing directly to this company at 51 Oregon Ave., Hamden 17, Conn.

•

Fabricated Products

Fabricated heat exchangers for process industries application—involving gas to gas, liquid to liquid, liquid to gas, powdered solid to liquid, high pressures to vacuum and temperatures from 280 to 1600 F—are described in a new 12-page booklet published by the M. W. Kellogg Co., a subsidiary of Pullman Inc.

The booklet also shows heat-treating facilities at Kellogg, which are capable of handling vessels up to 13 ft in diameter, up to 80 ft in length.

Copies of the booklet may be obtained from the Fabricated Products Division, M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

Sciaky Machine Catalog

Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill., announce the release of their Bulletin 333—*General Machine Catalog for Electric Resistance Welding*. This 12-page bulletin is divided into four sections—Industrial Applications, Manufacture and Service, Principles of Operation, and Types of Electric Resistance Welding Machines.

For complete information of the Sciaky line of resistance welding machines and philosophy of design and fabrication, write direct to the Chicago Plant for Bulletin 333.

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Iron and Steel Welding

"Recent Developments in the Fusion Welding of Iron and Steel," an 8-page article reprinted from *Metallurgia*, the British metallurgical journal, is available from Shieldalloy Corp., 99 Park Ave., New York 16, N. Y. Highlights of the discussion include coating ingredients; increasing use of low-hydrogen electrodes for the metal-arc welding of low-alloy steels; introduction of the inert-gas-shielded-metal-arc process with a consumable mild steel core wire; and the development of ferrite-controlled metal-arc electrodes for welding stainless steels. Illustrations include photographs, microphotographs, graph and tables.

•

How-to-Do-It Folder

A new how-to-do-it folder on welding, brazing, soldering and cutting steel with alloys and fluxes especially developed to minimize job costs is now available from All-State Welding Alloys Co., Inc., 249-55 Ferris Ave., White Plains, N. Y.

The folder is pocket size, but into its total of only 200 sq in. of printed area are condensed operator instructions on 14 of All-State's most popular alloys and their companion fluxes for application to various kinds of steel by torch and arc.

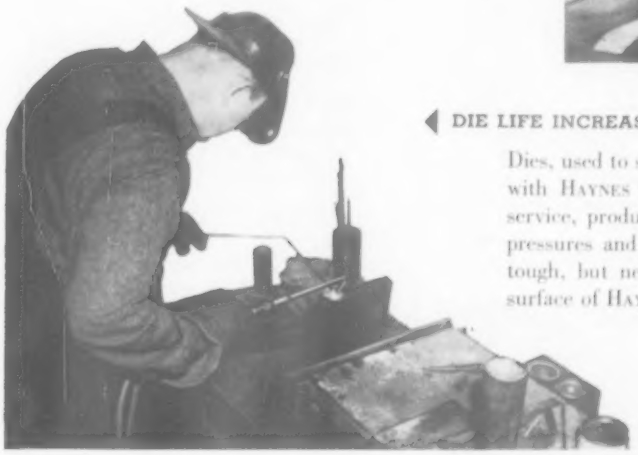
Featured are: a high-speed chamfer rod, a special electrode that supposedly will not freeze to the work if held too close, a paste solder and a cold-applicable metal filler.

Free copies are available on request to the company or to any All-State distributor.

Hard-Facing Helped Here...it Can Help You Too!

LIFE INCREASED 400%

Hard-facing these entry guides with a wear- and heat-resistant HAYNES STELLITE alloy increases their service life from 4 to 5 times. Unprotected guides failed after handling only 40 tons of hot steel bars, while the ones protected with HAYNES STELLITE alloy handled up to 200 tons. The guides are subjected to continual abrasion and heat from the hot steel passing through them.



DIE LIFE INCREASED 500%

Dies, used to shape refractory tile, last 5 times longer when hard-faced with HAYNES STELLITE alloys. Hard-faced dies have given 10 years' service, producing up to 500,000 tiles. The dies have to resist high pressures and abrasion from dry press operations. Unfaced dies are tough, but need the wear-resistance gained from a hard, protective surface of HAYNES STELLITE alloys.

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There are 14 different HAYNES hard-facing alloys. Some are hard and abrasion-resistant, some are tough and ductile, capable of withstanding the shock of severe impact; others give extraordinary service under conditions of corrosion, erosion, and heat. Descriptions of each alloy and procedures for applying it are included in the booklet, "HAYNES Alloys Hard-Facing Manual." Write today for your free copy.

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HAYNES *alloys*

Trade-Mark

Hard-facing products made from cobalt-base alloys, nickel-base alloys, iron-base alloys, and cast tungsten carbide in the form of tube rods and coils.

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Government Research Reports

Manufacturers and research laboratories are being urged to make more use of the growing stockpile of research reports released by the Federal Government through the Office of Technical Services (OTS) of the U. S. Department of Commerce.

The Government is conducting or sponsoring scientific and technical research at a current rate of more than $2 billion a year, mostly for defense purposes. By far the largest share represents applied research and development. This research generates a vast amount of nonconfidential technical information that is available to businessmen who are interested in developing new production processes, in making technological improvements, and in avoiding duplication of research efforts. Even ideas for new products have been sparked by these reports.

Some 350 such reports are described each month in U. S. Government Research Reports (formerly the Bibliography of Technical Reports) which is available from the U. S. Department of Commerce or any of its field offices at $6.00 a year.

The research covers nearly every field of industrial activity, including chemicals, plastics, paints, electrical machinery and electronics, foods, fuel and lubricants, instrumentation, leather, lumber, metals, minerals, paper, ordnance, physics, rubber, textiles, aeronautics, transportation, water supply and other items.

•

Stud Welding

A handy, "tell-at-a-glance" wall chart, furnishing condensed information on how end-welded studs of many shapes and sizes are used for various fastening jobs in the construction field, is now available on request from the Nelson Stud Welding Division of Gregory Industries, Inc., Lorain, Ohio.

The chart is illustrated with cutaway and simple line drawings of typical construction applications of studs, and shows the equipment with which studs are welded to steel in a split second. Available dimensions of the most commonly used construction studs are also listed.

The chart, second in a series being prepared by Nelson (the first covered studs in industrial applications), is included as part of a new "Cost Saver Kit." Mailed in a special tube simulating a threaded stud, the kit also includes a Nelson catalog and data sheets on specific construction applications when requested.

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11%-13½% Manganese-Nickel Steel
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TO FIT EVERY WORN TRACTOR GROUSER
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No. 300

Portable Brinell Tester

A new, 4-page, illustrated, two-color folder describing the King Portable Brinell Hardness Tester that makes standard Brinell tests and can be used as a bench tester or taken to the job and used in any position anywhere has recently been published by Andrew King of Ardmore, Pa. The folder describes how the precision instrument puts a load of 3000 kg on a 10-mm ball and other loads as required and how the removable test head makes it possible to test parts of any size which is an exclusive feature with the King Portable. The unit has a narrow and shallow nose at the anvil so that it can be used in small cramped spaces, tubes or cylinders.

For a free copy of the folder, write Andrew King, 67 E. Lancaster Ave., Ardmore, Pa.

•

Surface Preparation

An illustrated, 2-color bulletin—*Surface Preparation*—has recently been made available by the Protective Coatings Division of Metalweld, Inc., Scotts Lane & Abbottsford Ave., Philadelphia 29, Pa.

This bulletin points out the importance of proper surface preparation in all coating or painting applications.

Copies of this new piece of literature are available upon request to the manufacturer.

•

Service Failures of Metals

"Mechanical Failures of Metals in Service," by John A. Bennett and G. Willard Quick, National Bureau of Standards Circular 550, 36 pages, 102 figures, 1 table, 30 cents. (Order from the Government Printing Office, Washington 25, D. C.)

For many years the National Bureau of Standards has been requested to examine metal parts that have failed in service for evidence bearing on the causes of these failures. The examinations have been undertaken at the request of other Government agencies such as the Civil Aeronautics Board, the Interstate Commerce Commission, and the Coast Guard.

This circular describes 35 such cases representing the most frequently observed types of failures. The factors of design, fabrication or use contributing to these failures are presented. The characteristics by which the various types of fractures can be recognized are discussed, and recommended precautions that should be observed to reduce mechanical failures of metals in service are included.

Miller Selenium Rectifier Type D.C. Arc Welders

. . . performance, dependability, ease of maintenance unmatched by any other! *Pulsating* direct current produces sounder, denser welds; minimizes magnetic arc blow and "arc-outs." SR Welders have wider ranges than any other D.C. welder; polarity reverses at the flick of a switch. Miller's patented UNITRAN *combines* transformer and flux diverter. Easily remote controlled or paralleled in combination with other SRs. Models with rated outputs (60% duty cycle at 40 volts) of 200, 300, 400 and 600 amperes.

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Miller Heavy-Duty Industrial A.C. Arc Welders

These transformer-type welders achieve high-quality welds at maximum production speeds, feature low maintenance and long life. Ample open circuit voltage stabilizes arc, minimizes "arc-out" time, permits use of all A.C. or A.C.-D.C. electrodes. Continuous current control. Models 102, 103, 104, 105 and 106 rated at 200, 300, 400, 500 and 600 amperes respectively (60% duty cycle at 40 volts). Power factor correction at slight additional cost. Models 105-SA, 107-SA, 108-SA and 109-SA are specifically designed for submerged arc welding, have selective open circuit voltages for automatic welding. Rated secondary amperes (60% duty cycle at 40 volts) are 500, 750, 1000 and 1500 respectively. All SA models are power factor corrected.

20% PLUS FACTOR

Engineer-earned designator for the basically better design, high-quality components, established efficiency and longer life of Miller welders. Complete FREE literature upon request. Get the facts TODAY!

Miller Constant Potential Rectifier Type Sigma Welder

Model SIGMA-5 maintains stable welding conditions regardless of arc variations. Operator can set wire feeding speed on SIGMA head and arc voltage on SIGMA welder. After arc is struck, Model SIGMA-5 automatically regulates filler wire speed and current to maintain constant arc length. Power for SIGMA head and control circuit furnished from within welder. May be paralleled and/or remote controlled. 500 ampere rated output on 100% duty cycle at 30 volts.

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ELECTRIC MANUFACTURING COMPANY Inc. • Appleton, Wisconsin

Seamless Welded Tubing

Designers and fabricators of aircraft parts, engines, valves, pumps and machine parts in the process industries, appliances, or industrial equipment will find a new folder on stainless mechanical tubing of interest and value. This 6-page folder—"B&W Seamless or Welded Stainless Mechanical Tubing"—published by the Tubular Products Division of the Babcock & Wilcox Co. outlines the many advantages offered to design and fabrication engineers who consider tubing in the production of parts and products which they manufacture. In addition to defining the many finishes, size ranges, types and shapes of stainless tubing available to industry, the folder contains a table of condensed properties and processing data for nine popular grades of stainless tubular products.

Copies of this new folder, known as TB 365, are available free upon request to the division's general sales offices at Beaver Falls, Pa.

•

Weld Insert Process

A 10-page bulletin issued by the Arcos Corp., Philadelphia, describes a new welding technique known as the EB Weld Insert Process. This process, developed by the Electric Boat Division of General Dynamics Corp., permits deposition of a root pass which produces a smooth and uniform weld surface even though the actual welding is done on one side only. The process and the insert used with the process are especially suitable for the butt welding of stainless and alloy steel pipe, both seamless and welded. Information in the bulletin covers applications, compositions, dimensions and detailed specifications. Complete step-by-step information, with sketches and photographs, explains how to use the insert and process. Recommended filler metals for finish welding are also listed. Copy available upon request to Arcos Corp., 1500 S. 50th St., Philadelphia 43, Pa.

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WELDING SHOW

JUNE 8-10

MUNICIPAL AUDITORIUM

KANSAS CITY

•

BRING A TEAM FROM YOUR PLANT

REVIEWS OF NEW BOOKS

French Textbook on Welding

Les Soudures, by D. Seferian, Doctor of Sciences and Mining Engineer. Price, 3600 francs. 428 pp., with 299 figs., 2nd ed., 1954. Published in French by Dunod, Editeur, 92, Rue Bonaparte, Paris.

The first edition of this book was devoted to a study of the two principal welding processes, oxy-acetylene welding and arc welding; also, it contained a discussion of the various phenomena related to weldability. In this second edition, the author has developed further the section dealing with the weldability of metals, methods of testing welds and the metallurgical aspects of welding.

Other welding processes which have been developed during recent years are also treated. Thus, the reader will find new chapters on automatic arc welding, hard surfacing, stud welding and resistance welding.

This book is intended to be of help to engineers, technicians, foremen and all others interested in obtaining an answer to the welding problem with which they are faced every day.

THE NEW LOOK IN WELDING

• It's SYSTEMIZED protection featuring **coordinated** use of specially designed, lightweight curtains and tarps. For vertical protection . . . easy to hang glass cloth StaSafe curtains with flame retardent compound effectively deflects sparks and globules of hot metal.

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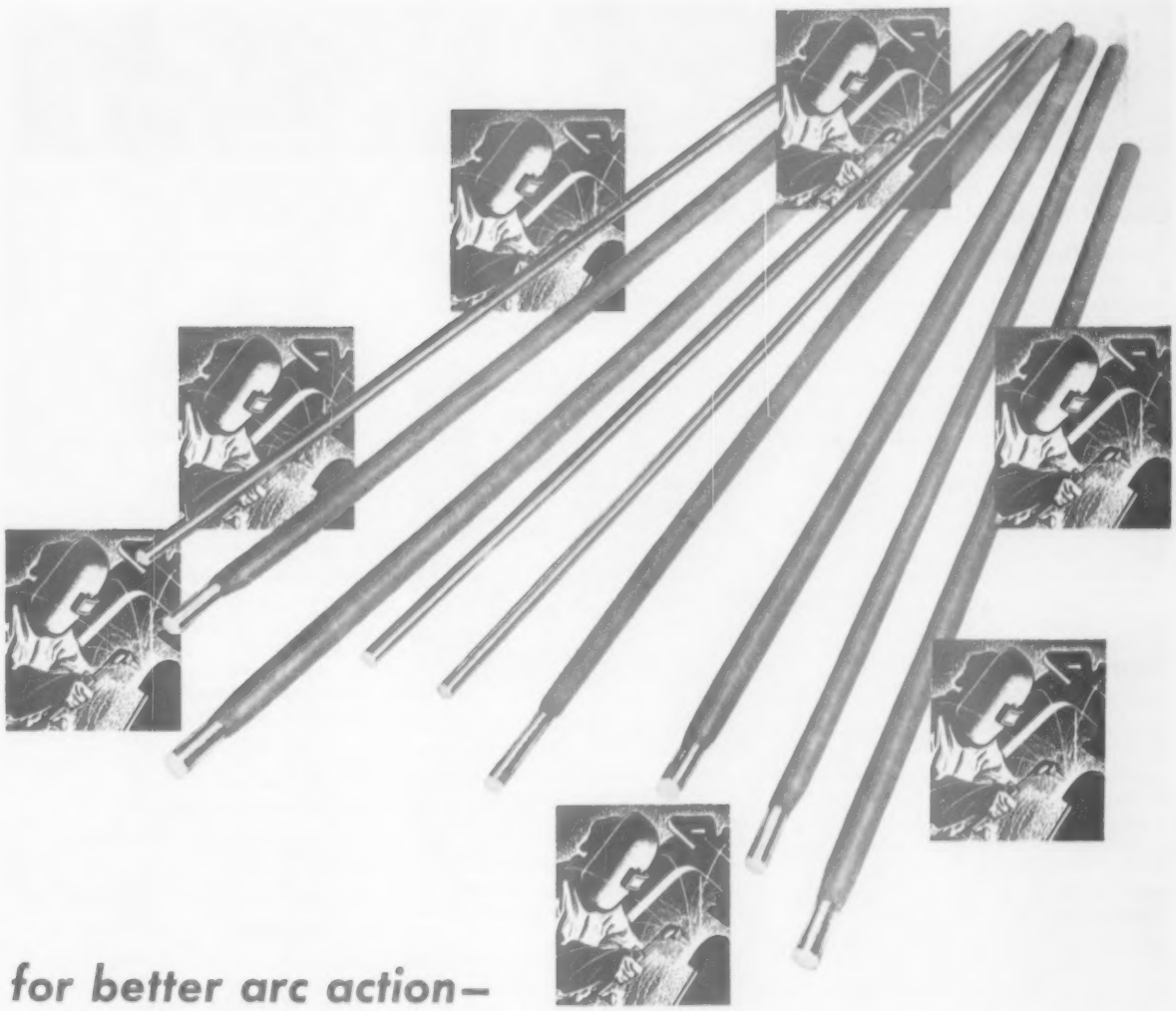


for better arc action—

USE CRUCIBLE REXWELD, *hard-facing rods*

Rexweld low hydrogen coated electrodes are easy to apply. That's because they provide improved weldability . . . more stable and direct arc. Welding can be performed both in vertical and horizontal positions. And with Rexweld you'll get denser welds . . . no porosity. Parts will resist chipping, deformation or heat checking better . . . and they can be Rexwelded again and again.

Get Rexweld rods from your local Crucible warehouse in both low hydrogen coated electrodes and bare rods, in a wide range of grades and sizes. Next time you have a hard-facing application use Rexweld. *Crucible Steel Company of America, Henry W. Oliver Building, Pittsburgh 30, Pa.*

CRUCIBLE first name in special purpose steels

Crucible Steel Company of America

NEW PRODUCTS

Contact Electrode

Eutec-HandOmatic No. 2, a new a-c, d-c contact-arc gap electrode for welding carbon steel has been announced by Eutectic Welding Alloys Corp., Flushing 58, N. Y.

According to the manufacturer, dense deposits of high-quality weld metal make Eutec-HandOmatic No. 2 ideal for carbon steel forms and plates, tank fabrication, containers, machines, overlaying shafts and bearing surfaces, cover beads, fillets of exceptional appearance and more economical welding with no chipping.

•

Moisture Tester

Weldrod Co. announces the development and introduction of its new Electrode Coating Moisture Tester. It is applicable to all electrode users who are welding with stainless, nonferrous and low-hydrogen rods and to electrode manufacturers and government installations. This new tester is reportedly quick and accurate for industrial use. Data available upon request from Weldrod Co., Meadowbrook, Pa.

•

Silver Brazing

The Air Reduction Sales Co. has just announced the new "Aircosil" products—a brand new and complete line of silver brazing alloys and flux. Aircosil alloys are available in various forms—rod, wire, sheet, rings and gaskets, as well as special shapes. Alloys of special composition to fit any production requirement are also available. The new Aircosil silver brazing flux is in paste form and reportedly will not freeze, crystallize nor separate and the residue rinses off easily in hot water.

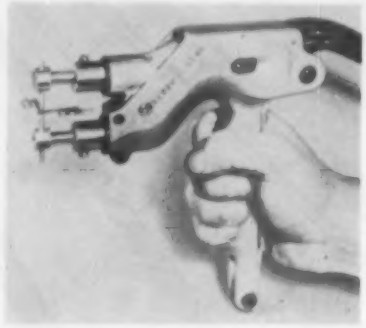
According to the manufacturer, Aircosil joins practically all ferrous, nonferrous and dissimilar metals and alloys that have melting points above its free-flowing temperatures.

Aircosil is sold by avoirdupois weight (16 oz/lb), rather than troy ounces.

For complete information about the new Aircosil alloys and flux, send for a copy of the Aircosil Brazing Booklet by writing Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Weld Gun

The Federal Tool Engineering Co., 1388 Pompton Ave., Cedar Grove, N. J. offers a new portable welding gun known as the "Tweezer-Weld" Gun.



This gun, according to the manufacturer, will weld materials from 0.003 in. to the combined thickness of 0.074 in. A lightweight, rugged aluminum unit ($2^1/_2$ lb), it will develop electrode pressures from 1 to about 50 lb with a light hand squeeze pressure. It is claimed that spot welds are made as fast as the operator can squeeze and release the trigger.

The "Tweezer-Weld Gun" is operated from extremely flexible copper, vinyl covered leads and is only 8 by 8 in. in size.

Accessories necessary to operation are either a condenser discharge power supply or standard a-c equipment including transformer, nonsynchronous timer and heat control.

For further information write directly to the company at the above address.

•

Soldering Flux

A new flux has recently been developed by the American Solder and Flux Co. According to this manufacturer, it is used by plumbers for joining copper tubing, does not contain any grease or binding material and eliminates steel wool cleaning of joints to be soldered. This flux, called C-Flux, also supposedly tins the metal as it cleans, permitting solder to flow smoothly with deep penetration. It is available in 3-oz and 1-lb cans.

For additional information, write the American Solder and Flux Co., 19th and Willard Sts., Philadelphia 40, Pa.

Alloy Electrode

A nonheat-treatable electrode, intended for welding highest alloy steels, has been announced by All-State Welding Alloys Co., Inc., 249–55 Ferris Ave., White Plains, N. Y.; it can be work hardened to over 180,000 psi tensile strength. According to All-state, deposits from this electrode maintain their very high strength at elevated temperatures; also, they are characterized by high corrosion resistance, hardness and wear resistance.

This new electrode is an alloy of chromium and nickel and is applicable with a-c or d-c welders. It is particularly designed for steel parts subjected to high heat, impact and corrosion. It is recommended by the manufacturer for use on very high alloy steels, tool steels, spring steels, pressure vessels, mild and medium carbon steels, and air-hardenable steels. Its as-welded properties include: tensile strength, 120,000 psi; elongation in 2 in., 25%; and hardness, 200 Brinell.

This work-hardenable alloy is designated as All-State No. 275 chrome-nickel (AC-DC). It is now available in $^3/_{32}$, $^1/_8$, $^5/_{32}$ and $^3/_{16}$-in. core sizes.

•

Stud Welding Gun

A new and more versatile stud welding gun was introduced at the National Metal Exposition in Chicago by Nelson Stud Welding Division of Gregory Industries, Inc., Lorain, Ohio.

Identified as the NS-9 the new streamlined gun marks the first comprehensive design change in Nelson-

The ambulances of Bowers Ambulance Service, of Long Beach, California, are the products of experts. . . .

Among the finest ambulances made in America are those of the Bowers Ambulance Service of Long Beach, California. From Cadillac Chassis to National Oxygen Regulator, no effort has been spared to select only tested, reliable, dependable equipment. When life hangs in the balance no mechanical trouble must have the slightest chance to tilt the scales against the patient.

Regardless of how much money you care to spend, you cannot buy finer single or two-stage reduction regulators than those made by NATIONAL of California. Whether for minute or vast hourly gas requirements, at very low or extremely high delivery pressures, no regulators will give you better service or more trouble-free performance than will . . . . . National

Because only the very finest equipment is chosen, National Oxygen Regulators are "standard" here.

No other regulator is so easy to adjust and no others will hold that pressure adjustment more steadily. Designed and built for the merciful hands of the hospital nurse, the sturdiness of these regulators will withstand the toughest operations in shop or field. Intended to sustain the flickering life of the injured or the ill, it will maintain the finest torch flame adjustment regardless of weather or gas volume.

One touch of the adjusting screw and you will know why NATIONAL of California regulators have won the test of time. Made by an organization with nearly half a century of experience **in the fields of high pressure gas equipment design and manufacture, you can rely upon these products.**

These regulators will require reconditioning but seldom; but, when they do, this job has been so simplified that any competent repair man, anywhere, can do so easily. . .

write for free brochure no. 4 —44 pages packed with interesting information and 30 color and black & white pictures.

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Tellurium-copper tips for long life. Positive flame and kerf control.
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All gas tubes silver soldered.
Precision drilled mixer, minimizes flashback. Complete mixing for maximum economy.
Comfortable, quick action cutting oxygen control lever.
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Large, straight line drilling provides an ample supply of cutting oxygen.
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stud-welding equipment during the 10-yr period in which more than 12,000 guns have been delivered to leading manufacturers, shipbuilders, railroads and construction industries all over the world.

The new gun will be made available with two different sizes of cable, one for welding studs with diameters up to $^1/_2$ in. and the other for any diameters from 10-gage up to 1-in. and greater.

Virtually unchanged as to weight, the new gun has a sweptback handle through which the cables enter a steel barrel that extends through the plastic gun body of which it is an integral part.

Additional information may be had by writing directly to the manufacturer.

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Inert-Arc Spot Welder

A manual consumable electrode inert-gas-shielded spot-welding process that makes spot, plug and tack welds with the addition of reinforcing filler metal was introduced at the National Metal Show, in Chicago, by Linde Air Products Co., a Division of Union Carbide and Carbon Corp. The process is claimed to overcome limitations of existing spot welding methods by making extra-strong welds in heavier metals, and by requiring access to only one side of the weld joint.

With this inert-gas-shielded welding process, spot welds are made by feeding consumable wire electrode automatically into the weld area. The filler metal makes a 100% penetration in the lapping metals. Spot welds can be made on metals up to $^1/_8$ in. thick, in a horizontal or vertical position. The process can be used on carbon and galvanized steel, stainless steel, copper-based alloys and other metals.

Apparatus can also be used to make plug welds on metals from $^1/_8$ to $^1/_4$ in. thick, and to make tack welds on all types of joints for subsequent welding. An operator can make up to 10 welds a minute, including positioning and post-weld argon flow.

Spot-welding machine consists of three main units: (1) a pistol-type, water cooled torch—lightweight and easy to use in hard-to-reach places; (2) a portable wire-drive unit which houses the rod reel and gas and water solenoids for instant shielding and cooling; and (3) a control box with Linde's new-style, built-in electronic controls. All controls are on a single plane. Special heavy-duty, industrial-type relays and timers are used for maximum dependability. The control box can be installed easily in any desired location.

•

Cold Weather Protectors

For cold weather use with their safety hats and caps, arc-welding helmets, headrest goggles and eyeshields, Jackson products has available Winterizers of strong, sanforized twill, lined with soft, warm, napped flannel. They're washable and hold their shape and color.

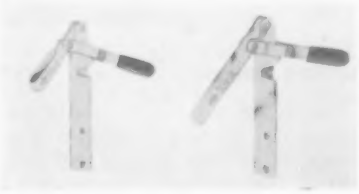
Coleap (right) protects top of head, *Frigicap* (left) covers head and ears. For bulletin and prices write to Jackson Products, Inc., Warren, Mich.

•

Clamps

Two more new clamp models have just been announced by the Detroit Stamping Co.

The new models, designated as 509-U and 509-S, also feature low silhouette, complete clearance of working area, flop-over action and the new red vinyl plastic safety-ease handle grip.



According to the manufacturer, the 509 Series is called Fixture Framers because of their angular-flange base which permits easy mounting by bolts or welding to side of fixture. The term Forty-Fivers is also applied because, when mounted vertically to side of fixture, the holding bars flop completely over side of fixture to produce a positive firm clamping action at a 45-deg angle directly against upright fixture base as shown in the accompanying illustration.

These clamps weigh 13 oz, with the 509-S's having a holding pressure of 500 lb and the 509-U's, 375 lb. Both the 509-U's and 509-S's are provided in both right- and left-hand styles.

A Bulletin 509 giving complete details on these DE-STA-CO Model 509's is available on request, according to William H. Roberts, Vice-President, Detroit Stamping Co., Detroit, Mich., who announced these new toggle clamps.

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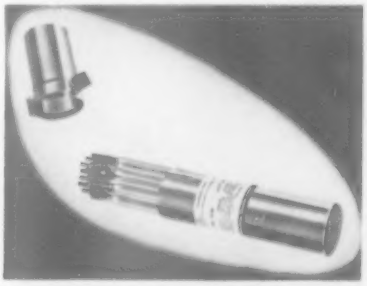
Electrode Container

A new package, designed, developed and produced in Canada to provide complete protection in shipment and in storage for Airco Stainless Steel Electrodes has just been released by Air Reduction Canada Ltd.



This package, conceived by Airco's engineering department, is composed of two seamless cylindrical sections of impact extruded aluminum. The top section or cap has an expanded rim which telescopes over the bottom section and is sealed airtight with a waterproof adhesive tape.

The new tubular container, which holds 10 lb of electrodes, can be opened without special tools by simply removing the tape seal and pulling off the top cap. As no metal is cut or removed when the container is opened, it can be resealed by merely replacing the cap and sealing tape.

Further information available by writing to Air Reduction Canada Ltd., 905 Hodge St., St. Laurent, Montreal 9, Que.

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Welding Lathe

The Unique Turntable & Equipment Corp., 1125 Irving Ave., Brooklyn 27, N. Y., announce the availability of their positioner *Welding Lathe*, Model—UWL series. It is made in weight capacities from 500 lb to 50 tons. The head and tail stock are both mounted on a track,

REDUCE YOUR ARGON WELDING COSTS.....

WITH THE New

ELEMATIC

Indicating and Recording Flowmeter

Elematic Flowmeters are specifically designed to give an accurate record of argon gas or oxygen flow for controlling and determining cost. They are adaptable to a regulated cylinder supply or a piped system.

Individual job billing costs can be charted. Quick check of welding apparatus efficiency is provided at all times. Insufficient flow can be immediately detected. Flow is permanently recorded for 24-hour or lesser periods on an easy-to-read chart.

Gauges available in two sizes: with 4½" chart from 0-15 LPM to 0-100 CFH; with 10" chart from 0-25 to 0-300 CFH. Both models are supplied for operation at approximate inlet pressures of 20 or 50 PSI, depending on specification.

APPLICATIONS:

Manual or mechanized shielded inert gas arc welding equipment. Heliarc Heliweld, Sigma, Aircomatic, Fillerarc

FEATURES:

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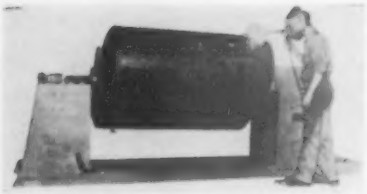
Write today for our new Bulletin on the complete line of Aluminum Wire—Spooled, Coiled, Straightened and Cut. For every aluminum welding job, Arcos offers the wire you need for the results you want. Arcos Corporation, 1500 South 50th Street, Philadelphia 43, Pennsylvania.

WELD WITH ARCOS

ALUMINUM AND STAINLESS SPOOLED WIRE



with the tail stock adjusting for work lengths desired, the tail stock has a hydraulic power ram revolving with the head rotation. The pressure exerted on the ram section is so made that it is controlled automatically.

Variations in this UWL series can be made to suit applications.

•

X-Ray Unit

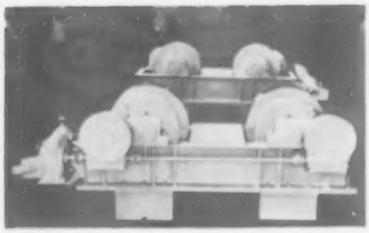
A new 160 kVp portable X-ray unit for industrial radiography is now available. It is reported to be lightweight and capable of X-raying 2 in. of steel.

The components are a tube unit weighing 120 lb, a control unit, 60 lb and lightweight connection and power cables. The unit operates on 110 and 220 v independent of separate transformers. Focal spot in the centrally located and X-ray tube is 1.5 mm, insuring sharp definition in radiographs. Manufactured and sold by Holger Andreasen, Inc., 703 Market St., San Francisco 3, Calif.

•

Turning Rolls

Worthington Corp.'s Positioning Equipment Division announces the broadening of their turning roll line with a new 200-ton capacity unit. According to the manufacturer, the Model 200 has been designed with an eye toward minimum floor space requirements, and is ideal for rotating vessels having many protuberances, as only one power and one idler unit is needed to handle a full 200-ton load.



Roller facings are only 7 in., thus assuring accessibility to most any type of tank. The power unit is driven by a 5-hp electronic variable speed drive, offering a range of rotation speeds from $3^1/_2$ to 56-in. per minute. Rollers are forged, each 34 in. in diameter, with the contact surface flame-hardened to reduce wear. Heavy-duty Timken Bearings are used throughout.

In addition to this new model and a standard line of rolls from $3^1/_2$ ton capacity and up, Worthington furnishes rolls of special design in capacities up to 600 tons.

For full information and specifications address Paul Galton, manager, Positioning Equipment Division, Worthington Corp., Plainfield, N. J.

•

Plastic Head Shields

Two new molded fiber glass plastic head shields for the head protection of welding operators are being announced by Hobart Bros. Co., Troy, Ohio.

Made of fiber glass reinforced plastic, reported to be the strongest protective material per ounce of weight, these shields offer the user lighter-weight comfort with complete head protection from the welding arc and spatter. Fiber glass plastic is durable, heat and moisture resistant, and its smooth, attractive surface is easy to clean.

Type 971 has the lens holder molded right into the shield to eliminate light leaks and to further reduce the weight.

Type 973 is of the same general design and plastic construction, except

ARCOS FOR FINEST QUALITY WELDS

Welded manifolds handle a hot problem

For maximum efficiency, the engines of fast-flying bombers and skycruisers operate at high temperatures. Exhaust manifolds get red hot . . . actually spit fire. Manifold materials and the welds *must* meet unusually rigid specifications.

On critical applications like this, Arcos Stainless Rods and Electrodes will produce the welds that will *not* fail under the terrific heat and vibration involved. When you need weld metal of this caliber for severe service, remember that Arcos filler metals are triple tested—each grade for its physical, chemical, and metallurgical qualities. Conscientious quality control by Arcos eliminates the expense and uncertainty of trial and error welding. In less time . . . at less cost, you get dependable welds for longer service. For proof—order Arcos Stainless Rods and Electrodes for your next tough job.

Arcos Corporation, 1500 South 50th Street, Philadelphia 43, Pa.

WELD WITH ARCOS

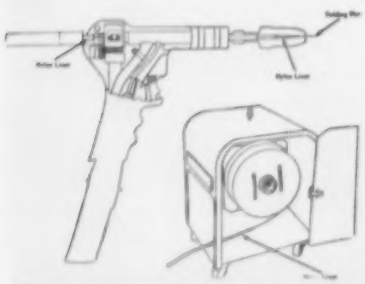
STAINLESS RODS AND ELECTRODES

that it has a lift front lens holder to permit the operator to view, chip and clean the weld without raising the hood. Both shields are equipped with federal specification lens. For complete information, write Hobart Bros. Co., Troy, Ohio.

•

Nylon Tubing Aids Welding Wire Transmission

Nylon tubing liners for transmitting welding wire have been adopted by the General Electric Co., Weldpower Division, York, Pa., to enable high-speed welding of metals by the inert-gas-shielded arc process.



Reportedly, the nylon tubing is suitable for the handling of aluminum, stainless steel, copper, nickel, magnesium, aluminum bronze and other weld metals.

Design of the equipment called for a smooth casing inside a flexible hose which can transmit the welding wire from coils to the gun. To insure an even feed, the hose or tubing had to be smooth, resist abrasion and have low friction against the welding wire. Moderate flexibility and resilience in the tubing were other important requirements.

The material adopted for the job is Polypenco FM-1001 nylon supplied by the Polymer Corporation of Pennsylvania, Reading, Pa.

•

Helmet Attachment

A new method for economically attaching a welding helmet to a safety cap is embodied in the "Two clips and neoprene strap" device recently designed and now manufactured by the Fibre-Metal Products Co., Chester, Pa.

According to this company, quick installation of the "Speedy Attachment" to helmets in the field is done merely with a screwdriver or a coin. The welder then can instantly attach or

detach the safety cap which is "clipped" into the helmet under the tension of the neoprene strap.

No basic alteration of either the helmet or safety cap is necessary. The "Speedy Attachment" reportedly fits all popular peak-type safety caps for complete head protection.

•

ATTEND

1955 AWS National Spring Meeting

Hotel Muehlebach
Kansas City, Mo.
June 7–10

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Square D's High-Speed Electronic Welder Control

faster! More spot welds per minute for repeat gun or machine welding operations . . . obtained by providing an additional SQUEEZE DELAY timing and a negative HOLD time sequence.

more consistent welds! Synchronized firing of ignitron tubes (welder transformer) and full cycle conduction provides uniform heat for each weld. Vastly improves quality of work.

less maintenance! Control unit uses heavy duty relays and components specifically designed for high speed welding service. Minimizes down time.

plus safety! Square D Fail-Safe tube circuits do not require conduction of an electronic tube to stop the weld . . . less possibility of danger to the operator and damage to the machinery.

dual SEQUENCE ADJUSTMENTS . . . provide complete control of two welding guns operated from one welder transformer and controller.

Write for High Speed Welder Control Bulletin #8992. Square D Company, 4041 North Richards Street, Milwaukee 12, Wisconsin.

SQUARE D COMPANY

Section News and Events

as reported to Catherine O'Leary

INERT-ARC WELDING

Fort Wayne, Ind.—One hundred and fifty-six members and guests of the *Anthony Wayne* Section met on Thursday, November 18th, in the Ball Room of the Hotel Spencer in Marion, Ind.

A 20-min talk entitled "Carbon Dioxide as an Inert Gas Shield" was given by Fred Zimmerman, Welding Engineer of Alloy Products Co., Marion, Ind. Mr. Zimmerman gave an interesting description of the development work at Alloy Products Co., toward perfecting the use of CO_2—first, as a backing shield and, later, as an arc shield, for inert-gas metal-arc welding, with both consumable and nonconsumable electrodes, on aircraft engine parts. These methods now have the acceptance of several large engine manufacturers because of improved weld quality as compared with argon and helium on crack-sensitive alloys, chrome nickel and carbon steels. Mr. Zimmerman also described the changes in equipment which he found necessary to obtain satisfactory results. He confirmed the improvement in weld quality by exhibiting slides, showing groups of test samples, with charts indicating the comparative physicals and X-ray qualifications.

Mr. Zimmerman's talk was supplemented by Ed Vogel of Liquid Carbonic Corp., Chicago, Ill., who collaborated with him in this development. Mr. Vogel supplied comparative cost data and statistical data on flow rates, etc., which resulted from research work in their Chicago Laboratory. He told the meeting that their work was far from complete but he expected charts soon to be available which would suggest gas flow rates based upon current and voltage scales, wire feed speeds and other process variables.

The meeting then adjourned to the Alloy Products Co.'s plant, where numerous sample welds were made with CO_2 as a backing- and arc-shielding medium. The members and guests had ample opportunity to observe and study both the processes and results.

MULTISPHERES

Phoenix, Ariz.—Christian Arne, Chicago Bridge & Iron Co., Chicago, Ill., was guest speaker at the December 15th meeting of the *Arizona* Section. Mr. Arne spoke on Multispheres.

INSPECTION

Beaumont, Tex.—David L. Shall (MS), an engineer for Humble Oil Co., Texas, was the guest speaker of the December 2nd meeting of the *Beaumont* Division of the Houston Section. Mr. Shall's subject "Inspection" covered code and inspection compliance, quality of material, and workmanship, dimensional checks and safety in operation and compilation of corrected data.

A highly recommended film on pipe lines was shown before the meeting through the courtesy of the Shell Petroleum Co.

WELDING METALLURGY COURSE

Boston, Mass.—The special lecture course of six lectures on the subject of "Welding Metallurgy of Carbon and Low-Alloy Steels" was started on January 18th by the *Boston* Section and will continue on each consecutive Tuesday except February 22nd, ending on March 1st. The lecturer is Dr. Harry Udin (MS), Assistant Professor of Metallurgy at MIT. The lectures are taking place at the Sloan Metal

SECTION MEETING CALENDAR

MARCH 3rd

NORTHERN NEW YORK Section. Panetta's Restaurant, Menands, N. Y. "Welding, Soldering, Brazing of Aluminum," by C. Bruno, Reynolds Metals Co.

Technical Activities Display—WRC Bulletins, Standards and Recommended Procedures for Spot Welding Aluminum Alloys.

MARCH 4th

NORTH CENTRAL OHIO Section. Plant Visitation—Baldwin-Lima-Hamilton Corp., Lima, Ohio

MARCH 8th

NEW YORK Section. 6:00 P.M. Schwartz's Restaurant, 54 Broad St., New York City. "Welding Titanium and Titanium Alloys," by John J. Chyle, Director of Welding Research, A. O. Smith Corp.

DAYTON Section. 8:00 P.M. Dayton Engineers Club. "Contact Electrodes." Speaker to be announced.

WESTERN MASSACHUSETTS Section. Springfield, Mass. Joint Meeting with Connecticut Valley Section of Non-Destructive Testing Society. "Non-Destructive Testing in Welding," by Sidney Low, Chapman Valve Mfg. Co., Indian Orchard, Mass.

MARCH 15th

NEW JERSEY Section. 6:30 P.M. Essex House, Newark, N. J. "Welding Standards and Codes."

MARCH 16th

NORTHWESTERN PENNSYLVANIA Section. Erie, Pa. "Submerged Arc Welding," by representative of Lincoln Electric Co.

PITTSBURGH Section. "Quenched and Tempered Plate Steels for Pressure Vessel Construction," by Leon C. Bibber, Chief Research Engineer, Welding Research and Technology Div., U. S. Steel Corp., Pittsburgh, Pa.

MARCH 17th

RICHMOND Section. Richmond, Va. "Jigs and Fixtures for Welding," by A. N. Kugler, Chief Welding Engineer, Air Reduction Sales Co., New York.

MARCH 21st

ROCHESTER Section. Rochester, N. Y. "Welding Metallurgy," by Dr. W. D'Orville Doty, U. S. Steel.

MARCH 25th

MILWAUKEE Section. 6:45 P.M. "Inert-Gas Metal-Arc Consumable-Electrode Welding," by J. E. Fitzwater.

Editor's Note: Notices to be published in any one given issue must reach Journal office not later than the first of the preceding month. Give full information concerning time, place, topic and speaker for meeting.

Tractor parts rebuilt with

AMSCO LEADER AUTOMATIC ELECTRIC WELDER

Save contractor $10,000 over replacement parts, double service life

If you operate track-type equipment, here's an automatic electric welder that is a *must* for your maintenance shop. It will save you time and money, and radically increase service life of your present equipment.

See what it did for one construction outfit:

Operating five large track-type tractors, each with 12 bottom rollers, 4 carrier rollers, 156 track links, 78 grouser pads, 2 idlers, 2 sprockets and one dozer blade, replacement cost was figured to be approximately $13,800. Rebuilding these parts with the Amsco Leader cost approximately $3,700, or a saving of about $10,000. Plus the fact that the rebuilt parts gave nearly double the effective service life of the new parts.

See your local Amsco Distributor today. Ask him for complete details on the Amsco Leader. See for yourself how a new Amsco Leader can save you thousands of replacement dollars.

AMERICAN Brake Shoe COMPANY

AMERICAN MANGANESE STEEL DIVISION
Chicago Heights, Ill.

Processing Laboratory—Room 35-225, Massachusetts Institute of Technology, Cambridge.

CHRISTMAS DINNER MEETING

Chicago, Ill.—The annual Christmas Dinner Meeting of the *Chicago* Section was held on Friday, December 10th, at the Chicago Engineers Club. Over 75 gathered for a social period prior to the dinner. The Barber Shop Quartet entertained with many very well-sung numbers.

Following dinner, C. F. Jensen, Lighting Division, Westingouse Electric Corp., talked on the subject "What Next?" which was a most interesting discussion and demonstration of the latest developments in the field of lighting.

Bill Lillie showed slides that he had taken at the Houston and Buffalo Spring Meetings as well as slides of the Golf Outing held by the Chicago Section last June at the Nordic Hills Country Club.

WELDING PROCESSES

Cincinnati, Ohio.—To have a group of experts in all phases of welding at one's disposal for a couple of hours is a rare opportunity. The *Cincinnati* Section was indeed fortunate to have such a group available at the November Technical Session held on November 23rd. Resistance and fusion welding were delved into from the technical research point of view to the actual fabrication by such experts as I. W. Johnson AWS, General Electric Co., S. J. Whalen AWS, Technical Metals Research Co., H. F. Reid AWS, The McKay Co., Byron Koger, Mosler Safe Co., and F. J. Pilia AWS, Linde Air Products Co.

Coffee speaker was the midwest's most prominent sports announcer, Ed Kennedy, who told of his various experiences in the sports world.

MAINTENANCE WELDING

Cleveland, Ohio.—A timely subject, "Maintenance Welding" was discussed at the December 8th Technical Meeting of the *Cleveland* Section by L. C. Richardson AWS, of Eutectic Welding Alloys Corp. Mr. Richardson's talk dealt with procedures and data for reducing maintenance costs by welding. He explained how to do difficult welding operations and suggested new possibilities of preventative maintenance welding.

Coffee talk was given by Harvey Gottschall, investment counselor associated with Prescott and Co., Cleveland investment house, who discussed, "What Makes Us Tick." In his talk Mr. Gottschall explained the functions of the New York Stock Exchange in providing a market place for securities of the nation's leading business enterprises.

INERT ARC WELDING

Columbus, Ohio.—The December meeting of the *Columbus* Section was held at the Riverside Restaurant on December 10th. Technical speaker was J. Ward Cunningham AWS, of the Air Reduction Sales Co., New York. Mr. Cunningham's subject was "Comparison of Shielding Gases for Inert-Arc Welding with Consumable Electrode."

After the meeting a sound color film entitled "Operation Ivy" was shown by the Civil Defense Administration.

RESISTANCE WELDING ELECTRODES

Dayton, Ohio.—The regular monthly meeting of the *Dayton* Section was held on December 14th at the Dayton Engineers Club. A movie on atmospheric gases entitled "Whatever We Do," supplied by the Air Reduction Co., was shown at the beginning of the meeting.

Technical speaker was E. F. Holt AWS, Chief Engineer of the Welding Division, P. R. Mallory and Co., Indianapolis, Ind. He talked on resistance welding electrodes and electrode materials. He told how in resistance welding electrodes, both high electrical and thermal conductivity are desirable, so that they may be resistant to pressure yet conductive to electrical current while extracting the heat. Pure copper has the best conductivity, but will not stand up under heat and pressure, so that it is necessary to add alloying materials to it. These alloys never exceed 3% of the copper. The alloys, while improving the mechanical properties of the electrodes, tend to reduce the conductivity. He next described the various classes of alloys and their properties. Slides were then shown demonstrating the various types of electrodes and their applications for various types of work.

SEAM WELDING SYMPOSIUM

Detroit, Mich.—The *Detroit* Section was fortunate in having three outstanding speakers at their Seam Welding Symposium held on November 12th. The speakers were:

D. L. Knight AWS, of National Electric Welding Machines Co., who spoke on seam welding developments, and applications as used in all phases of industry.

S. Rockafellow AWS, of Robotron Corp., who spoke on new developments in controls, to handle higher production demands.

J. H. Cooper AWS, of the Taylor-Winfield Corp., who spoke on machine construction, and advancements in seam welding machines.

Mr. Crawford of the Yoder Co., explained the movie "Miracle In Metals."

Dinner speaker was W. F. Nank of the Detroit Edison Co. Mr. Nank emphasized growth in southeastern Michigan.

CHRISTMAS PARTY

Anderson, Ind.—The *Indiana* Section held its December meeting on Friday, Dec. 10, 1954, at Linders Restaurant in Anderson, Ind. The meeting was a combination "Ladies Nite" and "Annual Christmas Party." Smörgåsbord was the order of the evening, followed by a group of local entertainers and group singing. The Section was then treated to a most interesting lecture and demonstration of the development and use of Transistors by Harry Gruelle of the Public Relations Department, Indiana Bell Telephone Co. This was followed by the distribution of door prizes in keeping with the holiday spirit.

PLANT TOUR

Des Moines, Iowa—Forty members of the *Iowa* Section enjoyed an educational trip through the Meredith Publishing Co. on October 21st. This company publishes the *Better Homes & Gardens* and *Successful Farming* magazines.

The trip started in the type setting and engraving room, showing the complete plate processing and rework procedures. Next came the job shop where the use of smaller plates in the single color presses were illustrated. Then came the visit to the five-color rotary processes showing actual operation of setting and aligning the plates so as to produce results with the proper shading of all colors. Next was a visit to the ink mixing department, the binding room, the mailing room and, finally, the maintenance shop. Conclusion of the trip, which was immensely enjoyed by a large group, took place in the cafeteria where refreshments were served.

FUTURE OF WELDING

Kansas City, Mo.—The *Kansas City* Section held its November meeting on Thursday, November 11th, at Fred Harvey's Pine Room, Union Station.

The principal speaker was Ted

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Here are reports from the field:

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"Beads have exceptionally smooth surface."

"In our book it surpasses any other E-6013 on the market."

"We think it's superior to all other 6013 electrodes in running characteristics."

"We find we can use it on more jobs than any other electrode we've tried."

NCG's new "CE" Electrode is designed to perform with maximum efficiency over a wider range of applications. It is usable in all positions with AC or DC straight or reverse polarity. Operators like this new rod because it is easy to strike and hold an arc, even with AC at low welding currents and low open-circuit voltages. There is little spatter; the arc is soft; action is quieter, with spray type metal transfer. Beads are smoother, with a fine, even ripple—free from pock-marks and slag inclusions. Slag deposits brush off easily. "CE" deposits with remarkable efficiency in any position. *Sureweld* "CE" conforms in all respects to E-6013 specifications. Your NCG dealer or nearest NCG office will be glad to demonstrate this new rod and let you try it for yourself. Contact him today.

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EVERYTHING FOR WELDING

Jefferson AWS, Editor of the *Welding Engineer*. Mr. Jefferson gave a very interesting talk on "What's the Future of Welding."

The Section was also honored with the presence of J. G. Magrath, National Secretary, who discussed the forthcoming AWS National Spring Meeting which will be held in Kansas City, June 7, 8, 9 and 10, 1955.

WELDING OF TANKS

Allentown, Pa.—A. R. Meyer AWS, of the Graver Tank & Manufacturing Co., East Chicago, Ind., presented an excellent address on "Submerged Arc Field Welding of Tanks" at the December 6th dinner meeting of the *Lehigh Valley* Section held at Walp's Banquet Hall, Allentown, Pa.

ROUND TABLE DISCUSSION

Mishawaka, Ind.—An informal problem and answer session of the *Michiana* Section, participated in by most of those present, took place on December 9th, at the Red Barn Restaurant, Mishawaka, Ind. Because of the very hazardous condition of the highways in most of the area at the time the attendance at this meeting was less than half of that expected. However, those who were present had a pleasant social time.

The meeting was turned over to John Grodrian AWS, Director, Factory Laboratory, Bendix Products Division, Bendix Aviation Corp. Mr. Grodrian acted as Moderator of a round table discussion of the welding problems encountered by various members of the group.

This was an informative and interesting meeting characterized by maximum group participation rather than by a formal program.

WELDING OF PLASTICS

New York, N. Y.—"The Welding of Plastics" was the title of the Technical Program at the December 14th meeting of the *New York* Section. Dr. J. A. Neumann AWS, President of the American Agile Corp., Bedford, Ohio was the speaker. Dr. Neumann started welding as a hobby. He gave a fascinating talk on the weldability of plastics and explained the most frequent applications for the chemical industry. His talk was illustrated by a series of slides, which showed the applications on pipe lines, duct lines, fans and vessels manufactured of polyethylene and polyvinyl chloride.

In addition to explaining the actual welding methods he also explained the materials, such as thermoplastic rod material and the type of gun that is used in the operation.

A lively discussion followed the talk and although the particular material was unfamiliar to the majority of the audience, it had such fascinating aspects, due to the similarity to welding of steel or metals, that the evening was most successful.

The meeting was held at Schwartz's Restaurant, 54 Broad St., New York City, where dinner was served prior to the Technical Session.

CONSUMABLE INSERT WELDING

Philadelphia, Pa.—The *Philadelphia* Section served as host for a joint meeting with the Society of Naval Architects and Marine Engineers on December 20th at the Engineers Club.

J. V. Harrington, Chief Projects Engineer for Electric Boat Division of General Dynamics Corp., spoke on "Consumable Insert Method of Root Pass Welding." With the aid of slides and actual welding specimens taken from stainless pipe being welded at Electric Boat, Mr. Harrington delivered a most interesting message at the joint meeting. It was pointed out that by the use of the spacer ring, which is consumable in the pipe joint, that the joints are not only clean inside but that the obstruction of each joint is considerably reduced. Argon gas is used both inside and out to prevent oxidation.

FLAME PLATING

Seattle, Wash.—The regular monthly meeting of the *Puget Sound* Section was held on December 9th at the Engineers Club in Seattle. A semitechnical talk on "Tungsten Carbide Flame Plating" was given by G. B. Ray of Linde Air Products Co.

CUTTING

Seattle, Wash.—"Ferrojet Cutting" was the subject of a semitechnical talk given by A. F. Chouinard AWS, of the National Cylinder Gas Co., Chicago, given at the November 11th dinner meeting of the *Puget Sound* Section held at the Engineers Club.

WELDING MACHINES

Rochester, N. Y.—A new meeting place for the *Rochester* Section meetings proved to be ideal from all standpoints when the November 15th meeting was held at the Liederkranz Club in Rochester.

The guest speaker, Harley Orr AWS, of Hobart Brothers Co., gave a very interesting discussion on the use of constant voltage welding machines with automatic and semiautomatic welding equipment. Mr. Orr had some excellent slides showing the application of constant voltage welding to existing automatic welding processes. He also showed slides of new automatic equipment.

The Section was happy to have Clarence Jackson of Buffalo, District No. 3 Director and Dr. G. E. Claussen, also of Buffalo, visiting the group. Mr. Jackson described the new arrangement of districts and discussed some of the activities of the SOCIETY on a national level.

LADIES NIGHT

Saginaw, Mich.—The *Saginaw Valley* Section had a very successful Ladies Night Program at the High Life Inn, Saginaw, Mich., on December 9th. The event was attended by 124 members and guests.

After the family style dinner, a short color movie on the Alaskan fur seal was shown followed by a talk by Mrs. Norma Friend of Greenblatts Furrier of Flint, Mich. Mrs. Friend was accompanied by professional models who modeled a complete line of furs, dresses and accessories. The program was very well received.

CHRISTMAS DINNER PARTY

St. Louis, Mo.—On December 3rd the *St. Louis* Section held its annual dinner dance at the Norwood Hills Country Club. Hal Havird's orchestra provided the musical background and all attending had a delightful time.

CHARTER MEETING

San Jose, Calif.—The *Santa Clara Valley* Section with headquarters in San Jose, Calif., had its Charter Night Meeting on November 23rd. The dinner meeting was held at the Red Barn Restaurant on South Monterey Road. Most of the 152 members who had signed up by charter night or had transferred into the Section were present for the occasion. Organization of the Section started in late August with meetings held in September and October preceding the granting of the Charter by the Board of Directors on November 4th.

At this Charter Night Meeting an election of officers was held with the following men elected to office:

Chairman—Mansfield M. Griffith, Food Machinery & Chemical Corp., San Jose, Calif.

First Vice-Chairman—Wallace J. Erichsen, Westinghouse Electric Corp., Sunnyvale, Calif.

Second Vice-Chairman—Fortune

than any other electrode we've tried."

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Strong, tough USS "T-1" Steel improves performance . . . reduces costs

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In "T-1" you get great strength (a yield strength of 90,000 psi.), yet you can fabricate this steel easily and at low cost. You get a steel with good creep and rupture resistance at temperatures as high as 900° F., yet so inherently tough that you can also use it in heavy duty jobs at *sub-zero* temperatures down to −40° F. In "T-1", in brief, you get a steel that withstands severe impact abrasion and, at the same time, resists corrosion at all temperatures.

This unique combination of properties helps you to cut costs and improve performance in an extremely wide range of industrial applications.

"T-1" enables you to reduce the size and weight of heavily stressed or heavily abused parts with no sacrifice in service life or dependability . . . and it enables you to increase the load handling capacity of excavating, hauling, or storage equipment with no increase in physical size or weight.

You can use "T-1" Steel to reduce fabricating costs, because you can weld it or flame cut it without pre- or post-heating. Heavy duty equipment now can be fabricated either in the shop or the field—wherever it is more convenient and less costly—without the lost time and extra expense involved in heat treatment. Remember, too, when you use "T-1" Steel to reduce the size of welded sections, you cut welding time and the amount of welding rod needed. That's more money saved.

You can use the high-temperature strength of "T-1" Steel to increase the service life of steel mill equipment and rotating machines. You can use its amazing sub-zero toughness and resistance to abuse in excavating and mining equipment that must operate outdoors in the most severe weather. In fact, with "T-1" Steel you can increase the strength, dependability, and safety of heavy duty equipment for use at *any* atmospheric temperature. Send the coupon for complete information.

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Masdeo, Hiller Helicopters, Palo Alto, Calif.

Secretary—A. G. Pond, A. G. Pond Co., San Jose, Calif.

Treasurer—Jack W. Garrells, Pacific Hardware & Steel Co., San Jose, Calif.

Honored guests for the occasion included:

C. P. Sander, Second Vice-President (National) AWS, Consolidated Western Steel Co., Los Angeles Calif.

C. M. Styer, District Director, Pacific Car & Foundry Co., Seattle, Wash.

Ray L. Townsend, Director-at-Large, Tweco Products Co., Campbell, Calif.

E. O. Williams, Past Director-at-Large, Victor Equipment Co., Los Angeles, Calif.

E. A. Daniels, President, International Acetylene Assn., Victor Equipment Co., San Francisco, Calif.

Following the dinner Mr. Styer read the letter of Charter Authorization sent by the National Office and signed by J. G. Magrath, National Secretary. Short congratulatory talks were given by each of the honored guests.

The speaker of the evening was Richard K. Lee, Vice-President, Alloy Rods Co., York, Pa. His subject was "Fundamentals of Welding Metallurgy." Mr. Lee's talk was excellent. A lively question-and-answer period followed it.

The program chairman, Wallace J. Erichsen, outlined the programs that were on schedule for the balance of the year.

ELECTION OF OFFICERS

Miami, Fla.—The newly organized *South Florida* Section announced the election of the following officers:

Chairman—Thomas R. Berg, Little River Station

First Vice-Chairman—Al G. Thompson, Miami Welding Supply, Inc.

Second Vice-Chairman—Paul Greenfogel, Vulkan Specialty Co., Inc.

Secretary—H. M. White, Little River Station

Treasurer—Leo R. Riedy, c/o Jorgensen & Schreffler Engrs.

Technical Representative—C. A. Young, Little River Station

STRUCTURAL WELDING

Miami, Fla.—The *South Florida* Section met on December 8th at the Miami Builder's Exchange.

Technical speaker was V. R. Saxe of Baltimore, Md. Mr. Saxe, a leading authority on structural steel welding and designing, gave a brilliant discussion on the various welding problems encountered in the structural field. Mr. Saxe showed a number of very interesting slides and distributed pieces of literature on various phases of this type of welding. A standing ovation was given the speaker at the conclusion of his talk.

SUBMERGED ARC WELDING

Syracuse, N. Y.—The regular monthly meeting of the *Syracuse* Section was held at the Hotel Onondaga in Syracuse, N. Y., on Dec. 8, 1954.

The technical speaker was J. M. Tippett of the Linde Air Products Co., who gave an interesting discussion of of Submerged Arc Welding Applications.

This talk was accompanied by a group of slides showing typical production setups employing submerged arc welding as a high-speed production tool. The main talk was followed by a very informative question-and-answer period.

The regular technical meeting was preceded by a well-attended dinner meeting which featured a discussion of problems involved in planning and building the New York State Thruway. This discussion was extremely interesting and thoroughly enjoyed by all those present.

INERT ARC WELDING

Sheffield, Ala.—The December 2nd meeting of the *Tri-Cities* Section was held at the TVA Auditorium. Dinner took place at the King Cotton Restaurant. Guest speaker was John McClendon AWS, of Air Reduction Sales Co., Birmingham. He gave a very interesting talk on "Inert Arc Welding of Aluminum and Stainless Steels." Mr. McClendon's talk was augmented with slides and film. There was a good turnout for this meeting; District Director A. E. Pearson was among those present.

Officers and speaker at *Tri-Cities* Section December meeting. (Left to right) E. Lindsey, Vice-Chairman; T. H. Shields, Secretary; F. H. Eckert, Chairman; John McClendon, guest speaker; A. E. Pearson, District Director

MULTISPHERES

Tucson, Ariz.—Christian Arne, Research Engineer, Chicago Bridge & Iron Co., was the guest speaker at the December meeting of the *Tucson* Section held at the Municipal Golf Course Dec. 14, 1954. Mr. Arne illustrated his lecture with slides and told about the "Construction of Spheres and Multispheres." Mr. Arne spoke about the manner in which the "Big" Sphere was erected for the Atomic Energy Commission and the problems that confronted the engineering department and how many of these problems were solved.

Prior to the meeting, the Section held a raffle on a welding helmet donated by Dye Oxygen Co. The helmet was won by speaker Christian Arne who in turn donated the prize to the Tucson High School to be offered to some outstanding welding student in the 1955 graduating class.

SYMPOSIUM ON ELECTRODES

Washington, D. C.—The Symposium on Consumable Coated and Contact Electrodes was held at Naylor's Restaurant on November 30th at the *Washington* Section. A panel discussion with questions and answers very ably handled by the panel consisting of the following: E. B. Lutes, Arcrods Corp.; R. Stratton, Lincoln Electric; J. Ray, A. O. Smith; C. R. Titus, Westinghouse; G. E. Linnert, Rustless Iron & Steel.

ALLOY STEELS

Washington, D. C.—A joint meeting of the *Washington* Section was held on December 13th with the local chapter of the ASM. Speaker was L. C. Bibber AWS, U. S. Steel, Pittsburgh, whose subject was the "Potentialities of Quenched and Tempered Alloy Steel as an Engineering Material."

RESISTANCE WELDING

Grand Rapids, Mich.—The December meeting of the *Western Michigan* Section was held on Monday evening, December 13, in the Varsity Grille Clubrooms. An excellent chicken dinner was enjoyed by 69 members and guests. For the coffee talk there were two members of the Grand Rapids Rockets hockey team.

The technical session was addressed by Jack Ogden AWS, Senior Engineer in charge of Process Development at Fisher Body in Detroit. Mr. Ogden is chairman of the Resistance Welding Committee of the Welding Research Council.

New Members

Effective November 30, 1954

A—Sustaining Member B—Member C—Associate Member D—Student Member E—Honorary Member F—Life Member

ANTHONY WAYNE

Houk, Robert C. (C)
Kirchhofer, Rufus (B)
McLain, James E. (B)
Nowak, Ted J. (C)
Terry, Lloyd E. (C)

ARIZONA

Redman, Don Lee (C)

BOSTON

Halliday, Robert J. (B)
Panetta, Alfred M. (B)
Ramsey, J. N. (C)
Weiss, Stanley (D)

BIRMINGHAM

Leopard, Robert H. (C)
Sawyer, Richard H. (C)

CANADA

Barrett, Geo. F. W. (B)
Llewellyn, Jehu (B)

CHICAGO

Coffin, B. R. (B)
Gerker, Joseph H. (C)
Grycko, Michael J., Jr. (C)
Hanover, J. L. (B)
Hunstiger, Oscar C. (C)
Luksha, Nicholas Wm. (B)
Schellenger, John M. (C)
Soso, Richard P. (C)
Ward, Leonard E. (B)
Weaver, Roy D. (C)
Wigton, Matt H. (C)

CINCINNATI

Matthes, Karl William (B)

CLEVELAND

Beal, William W. (C)
Howard, Frank, Jr. (B)
Staiger, George W. (C)
Williams, Donald C. (B)

COLUMBUS

Downing, Richie (C)
Elsasser, Arthur (B)
Gutridge, Lawrence C. (B)
Irwin, K. J. (D)
Lehmkuhl, Elmer J. (C)
Sukup, George (C)
Van Cleave, B. P. (D)
Walimire, Doyle W. (C)

DETROIT

Benton, W. (B)
Blower, S. (B)
Bosman, Robert (B)
Gagnon, Roy (C)
Gardham, John T. (C)
Harris, Doucias I. (B)
Leisberg, Armand C. (B)
Murdock, Ellsworth C. (B)
Pravel, Herman (B)
Royse, Jos. E. (C)
Soennichsen, Melchior (B)
Sonnichsen, Karl (B)
Taylor, Clark R. (B)
Schreiber, Walter (A)
Wilhelm, Thomas R. (B)

EAST TEXAS

Thompson, I. M. (B)

EASTERN ILLINOIS

Berkeley, John B. (B)

HOUSTON

Bevan, David H. (C)
Blackstock, C. E. (B)
Dillman, Charles M. (C)
Elliott, Richard J. (B)
Gaskin, Robert L. (C)
Joor, William E. II (C)
Lasater, T. C., Sr. (C)
Slay, Chester L. (B)
Timmons, J. W. (C)
Young, Nolan E. (B)

INDIANA

Palmer, David L. (B)

IOWA

Jones, Clayton J. (B)
Luellen, F. E. (C)

KANSAS CITY

Davis, Herbert A. (B)
Hermann, H. G., Jr. (B)
Hollandsworth, J. L. (B)
Johnston, Harold W. (B)
Shonka, Bernard J. (C)

LEHIGH VALLEY

Bergheimer, Lawrence W. (C)

LONG BEACH

Hogate, Ralph H. (C)

LONG ISLAND

Day, Edward L. (C)

LOS ANGELES

Benedick, Robert F. (C)
Jaffray, Ben (C)
Jardine, James (C)

MADISON

Adkins, Howard E. (B)
Brey, Howard (B)
Brockett, Edward (B)
Busby, Richard C. (D)
Cairns, John V. (B)
Chamberlin, W. H. (B)
Champnoise, Donald A. (C)
Drews, Harold E. (B)
Duncan, Louis C. (B)
Ehle, Arnold (B)
Ela, Richard E. (B)
Elliott, Clyde (B)
Endres, Lawrence (B)
Falch, Alex (C)
Friedrich, Athniel A. (B)
Fuller, Richard (B)
Gleesing, Theodore C. (B)
Gregory, John (B)
Herreid, Russell (C)
Hill, Elmer G. (C)
Hugo, Harold W. (B)
Koltes, R. J. (B)
Koltes, Tom (C)
Komlo, John W. (C)
Knudtson, Raymond (B)
Krueger, Melvin W. (B)
Mayer, A. H. (C)
May, Harold L. (C)
Milward, Claude (C)
Minter, Roy M. (B)
Mooney, Fred (C)
Mueller, Leonard E. (C)
Myers, Dwight (B)
Olson, Norman A. (C)
Perrier, Ralph J. (B)
Peters, Charles F. (B)
Pfaff, Dean D. (C)
Polinske, Charles H. (C)
Prosser, Cliff (B)
Remus, Allan L. (B)
Riddle, Victor (C)
Rosenow, F. Howard (B)
Schmid, Arthur C. (B)
Schon, Einar B. (B)
Schroud, Reuben (C)
Scott, Seth (B)
Skidmore, Edward J. (C)
Smith, Kenneth G. (C)
Ullenberg, Gordon A. (D)
Thiers, Werner (C)
Vedvik, Andrew (C)
Wagner, Karl (C)
Weiss, Benno A. (C)
Weyrough, Joseph T. (B)
Willis, Kenneth (C)
Wiltjer, Albert J. (C)
Winfield, Martin G. (B)

MAHONING VALLEY

Gardner, Raymond, Jr. (C)

MICHIANA

Closson, Jack R. (C)

MILWAUKEE

Groth, L. Arthur (C)
Patrick, Donald E. (C)
Wollering, Walter R. (C)

NEBRASKA

Bailey, Albert M. (B)
Bernstein, Robert (C)
Blechinger, Frank X. (C)
Breslow, David (B)
Brown, Arthur L. (C)
Burg, Marlo (C)
Burton, Kenneth D. (C)
Callahan, L. J. (C)
Church, Eugene (B)
Cozad, Eldon W. (C)
Cunningham, L. J. (B)
Dodd, William, Sr. (B)
Dunn, Don J. (C)
Edwardson, James H. (B)
Fieselman, C. C. (B)
Gaines, Douglas W. (B)
Gardner, Chas. B. (B)
Gauthreaux, O. J. (B)
Green, James R., Jr. (B)
Hale, Yeager (B)
Harney, L. R. (B)
Havener, Elton W. (B)
Hummel, Joe B. (C)
Johnson, Elmer H. (B)
Johnson, John D. (B)
Johnson, Reuben C. L. (C)
Knight, John B. (B)
Mahr, Eugene H. (B)
Marshall, John S. (B)
Mohrhusen, Theodore J. (C)
Monroe, C. W. (C)
Morris, Hal C. (B)
Petersen, R. E. (B)
Pflasterer, Fl. (B)
Schneiderwind, W. O. (C)
Schonlau, Harry A. (B)
Selser, Marion C. (B)
Stageman, J. W. (B)
Shull, Frank T. (B)
Steele, Henry W. (B)
Smith, Paul Y. (B)
White, C. E. (B)
Williams, Sylvester V. (C)
Yos, F. W. (B)

NEW JERSEY

Fleisher, Seymour (B)
Garrabrant, Edmond C. (B)
McGlone, Thomas J. (C)
McGrath, Frank J. (C)
Wilson, Raymond F. (B)

NEW ORLEANS

Labbe, John S. (B)

NIAGARA FRONTIER

Rendall, William A. (C)
Ross, John L. S. (B)

NORTH CENTRAL OHIO

Rolfe, Ralph E. (C)

NORTHEAST TENN.

Patriarca, Peter (C)

NORTHWEST

Cherveny, Milo J. (B)

NORTHWESTERN PENNSYLVANIA

Kennedy, R. C. (C)
Ostberg, Irwin C. (C)
Pepicello, Vincent, Jr. (C)

OKLAHOMA CITY

Barrick, Harley P. (D)
Combs, Clyde H. (D)
Davis, Bill R. (D)
Donohue, William Stephen (D)
Goleman, Ovie D. (D)
Haney, George (D)
Jeffries, T. R. (D)
McAlister, Eugene (D)
Moore, James D. (D)
Taylor, Harold Don (D)

PEORIA

Zimmerman, Franklin E. (C)

PHILADELPHIA

Bent, Sidney Thomas (C)
Freed, R. Russel, Jr. (C)
Gartner, Henry C. (B)
Litton, Felix B. (B)
Martin, David E. (C)
O'Brien, Joseph M. (C)
Opila, Francis A. (C)

PITTSBURGH

Barnes, Orville K., Jr. (B)
Kimmel, Ralph P. (B)
Hoener, Philip F., Jr. (C)
Speicher, Don E. (B)

PORTLAND

Struble, Glenn R. (B)
Taylor, J. W. (B)

PUGET SOUND

Killin, Amil J. (B)
Koepenick, Fredrick R. (B)

ROCHESTER

Oliveri, Alphonse M. (C)
Smith, Thomas E. (C)
Steele, Roy M. (C)

SAGINAW VALLEY

Wuepper, Earl J. (C)

SAINT LOUIS

Christian, Ralph R. (B)
Gurnea, Robert F. (B)
Kleefisch, Earl W. (B)
Leonard, Paul J. (B)

SALT LAKE CITY

Christiansen, E. A. (B)

SAN FRANCISCO

Gendar, Stephen C. (B)
Long, Darrell G. (B)
Mathews, T. J. (B)
Mueller, Kenneth P. (B)
Oster, Alan G. (B)

SANTA CLARA VALLEY

Armenta, Ray R. (B)
Arnold, S. P., Jr. (B)
Bain, William J. (B)
Barbano, George W. (B)
Barsuglia, Guido Jack (C)
Bateman, Robert G. (C)
Bedinger, L. K. (B)
Beightol, Wm. C. (B)
Bell, Francis E. (B)
Bianchi, Edward M. (B)
Biggs, Almond Ray (B)
Birdsell, H. J. (B)
Blake, Donald G. (B)
Blankenbaker, Charles R. (B)
Bowen, William Millen, (C)
Buckner, Harold L. (B)
Burrier, Clarence W. (C)
Bursk, LeRoy M. (B)
Butterfield, Harvey (B)
Butzback, J. E. (B)
Byer, William M. (C)
Carlton, Carroll T. (C)
Carney, Theodore T. (B)
Cartwright, E. V. (B)
Chaffin, Keith A. (C)
Chavarria, Primitivo (B)
Cipriano, Martinez D. (B)
Davis, Ellis V. (B)
DeVitto, Jack (B)
Dinardi, Leonard S. (B)
Dougherty, Robert J. (B)
Fager, Otis (B)
Field, Harry V. (B)
Flaherty, M. E. (B)
Furtado, Clarence (B)
Callahan, Lester B. (B)
Garcia, Joseph A. (B)
Garrels, Jack W. (B)
Gifford, T. C. (B)
Gilmore, Lovel J. (B)
Gladding, Albert James (B)
Gogliano, F. J. (B)
Gomez, R. Anthony (C)
Gonzales, Wm. J. (B)
Goss, Jesse Edwin (B)
Grafton, James W. (B)
Griffis, Domenic (C)
Gundo, Raymond (B)
Hayden, Leo M. (C)
Herrero, C. A. (B)
Howard, James T. (C)
Hudson, James B. (B)
Jimenez, Vincent (C)
Johnson, Melvin E. (B)
Johnson, Raymond N. (B)
Joyal, Frank F. (B)
Kutrovac, Nick (C)
Kinsey, Samuel A. (B)
Langlois, Ira (B)
Leutjen, Orie S. (B)
Macon, Roscoe A. (B)
Mauldin, Grover A. (B)
McAllister, George L. (B)
McDonald, Warren, S. (B)
McGuire, Harold Clark (B)
McLain, Loyd E. (C)
Meckler, Otto J. (B)
Meisser, Everett L. (B)
Michael, Archie (C)
Miller, Edward James (C)
Miller, Harold R. (C)
Moore, Mervin A. (B)
Moore, Roscoe W. (C)
Moore, W. H. (C)
Morgan, William W. (B)
Mulford, Edward E. (C)
Newton, George (C)
Newell, Louis O. (B)
O'Neal, W. Ray (B)
Oswald, A. H. (C)
Parker, Arlas O. (C)
Pond, A. G. (B)
Purcell, Rupert M. (B)
Ramirez, A. C. (B)
Ramirez, Pete (B)
Rech, Lawrence (B)
Richter, J. E. (B)
Rodriquez, Crispin C. (B)
Rosenquist, Lloyd E. (B)
Rossmann, Geo., Jr. (C)
Rugani, Bruno J. (C)
Russell, Gordon A. (B)
Sanchez, Joe A. (B)
Scapple, Robert Y. (C)
Sebastian, M. J. (C)
Shepard, O. Cutler (C)
Sims, John F. (B)
Skinner, Gilbert B. (C)
Skow, Ronald N. (C)
Sorensen, C. L. (C)
Souther, Carvel N. (B)
Spencer, Joseph L. (C)
Strohmaier, E. A. (C)
Tedrow, G. E. (B)
Thomas, Ralph Jack (C)
Thorsen, Martin (B)
Tomey, Alfred (B)
Turner, Jerry W. (C)
Vaillancourt, Don A. (C)
Wade, E. L. (C)
Whitmer, Johnathan M. (B)
Williamson, Ronald E. (B)
Wingate, Cameron F. (C)
Woodling, Robert W. (B)
Wright, William Robert (C)
Zambataro, Orazio (B)

SOUTH FLORIDA

Banning, Robert B. (B)
Banthen, Michael J. (B)
Benten, Joseph W., Jr. (B)
Berg, Thomas R. (B)
Besancon, Burrell (C)
Besancon, J. E. (C)
Biedelman, D. A. (C)
Bradford, Ben (B)
Carter, Nick (C)
Chauvin, J. A. (C)
Davis, Lloyd F. (B)
Dignum, Norman J. (C)
Echtle, Clemens H. (B)
Gibbs, Joseph E. (B)
Goerlitz, John, Jr. (B)
Greenfogel, Paul R. (B)
Hall, Morris A. (B)
Harllee, J. W. (C)
Hawkins, Chas. H. (C)
Hayberg, Charles (B)
Hayes, Raymond (B)
Higgins, Murray (C)
Hill, John Harvey (B)
Kahn, Norman (C)
Kennerk, Perry A. (B)
Knowles, Lee (B)
Martin, Robert S. (B)
Morgan, Walter (C)
Mount, Andrew W. (B)
Murphy, E. M. (B)
Otto, Charles H. (C)
Patterson, Leigh D. (B)
Penfold, P. (B)
Petit, Henry Eugene (C)
Poston, Ralph R. (B)
Reeder, R. Zee (B)
Riedy, Leo R. (B)
Robb, Allen T. (C)
Robb, Richard D. (B)
Rooney, Frank J. (B)
Ross, Harry J. (C)
Seabloom, David F. (B)
Seaman, Edward Warren (C)
Schneider, R. (C)
Silberger, Edw. M. (C)
Shinn, H. Clinton (B)
Smith, Al M. (B)
Stancil, Hoke S. (C)
Streeter, Clyde E. (C)
Thompson, A. G. (B)
Union, Stanley J. (B)
Vosser, Elmer R., Jr. (B)
White, H. M. (B)
Wingerter, Geo. E. (B)
Witt, R. P. (C)
Young, C. A., Jr. (B)

SYRACUSE

Mager, Robert F. (C)

TRI-STATE

Boewe, Howard L. (B)

TUCSON

Fry, Howard M. (C)
Hansen, Allen F. (C)

WASHINGTON

Hill, John L. (B)
Kimmel, N. Richard (C)
Mulitz, Milton M. (C)
Orden, David B. (C)
Scullen, Edward J. (C)

WESTERN MICHIGAN

Rice, Sherwood P., Jr. (B)
Rice, Sherwood P., Sr. (B)

WESTERN MASSACHUSETTS

York, Albert C. (B)

WICHITA

Swick, Clarence (B)

WORCESTER

Baer, William (B)

YORK CENTRAL PENNSYLVANIA

Eveson, Paul A. (B)
Himes, Glenn E. (C)
Hyde, Charles C. (C)

NOT IN SECTIONS

Ericsson, Curt (B)
Rao, Shri M. R. (C)

MEMBERS RECLASSIFIED

During the Month of December

Fegley, Vaughn S. (C to B)

ABSTRACTS OF CURRENT PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,695,941—Key Welding Machine—Alfred Treff, Chicago, Ill., assignor to Continental Can Co., Inc., New York, N. Y., a corporation of New York.

Treff's patent relates to a specialized machine for welding keys to can ends. These can ends have been punched to provide a raw metal peripheral edge portion and a cooperating pair of electrodes is provided, one of which engages the key and the other is in part frusto-conical in shape. Such other electrode engages in can end centering contact with the raw metal edge of the associated can end.

2,695,942—Work-Engaging Contact Equipment—Frederic M. Darner, Shaker Heights, Ohio, assignor to Republic Steel Corp., Cleveland, Ohio, a corporation of New Jersey.

This patent relates to welding apparatus having an arc electrode for welding action along a predetermined path on a work element. The electrode is connected for flow of arc current between it and the work and means are provided for moving one of the elements relative to the other to effect welding progressively along the path. A wire brush is present and is elongated in the direction of the path for engaging the surface of the work close to the electrode for a relatively considerable distance along the predetermined path. This brush is electrically connected to carry arc current between the work element and the source of the current and sweeps along the surface of the work element during operation of the movement producing means.

2,695,943—Weld Rod Coating—Arthur T. Cape, Los Angeles, Calif., and Charles V. Foerster, West Englewood, N. J., assignors to Coast Metals, Inc., Little Ferry, N. J., a corporation of Delaware.

The special weld rod of this patent has a coating thereon containing monazite, graphite and sodium silicate. The monazite is present in amounts up to 15% of the weight of the coating.

2,695,944—Electrode Holder—Thomas S. Donnelly, Jr., Detroit, Mich.

Donnelly's patent electrode holder has a jaw and a pair of side walls one of which is at each of the opposite sides of the jaw and projects outwardly from one face thereof. The jaw is slidable longitudinally of the electrode holder, and the side walls are specially positioned in the holder.

2,695,945—Refractory Metal Electrode for Inert-Gas-Shielded Arc Welding—Louis A. Conant, Tonawanda, N. Y., assignor to Union Carbide and Carbon Corp., a corporation of New York.

In this patent, a gas-shielded arc-welding electrode is disclosed. The electrode comprises refractory metal such as tungsten and it has mixed therein about 2% of yttrium oxide.

2,695,946—Inert-Gas-Shielded Arc-Welding Electrode—Louis A. Conant, Tonawanda, N. Y., assignor to Union Carbide and Carbon Corp., a corporation of New York.

Conant's patent is on a nonconsumable inert-gas-shielded arc-welding and cutting electrode. This electrode is composed of tungsten in which a minor amount, such as 0.5 to 10% of calcium oxide is dispersed.

2,696,545—Welding Apparatus—Hubert A. Myers, Hollywood, Calif., and Amos L. Quinlan, La Grange Park, Ill., assignors to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

This patent relates to apparatus for welding a contact onto a part and includes means for feeding an end portion of a tape of contact material onto the part, electrodes for welding the contact material to the part, and cutting means for cutting the tape from the welded section affixed to the part.

2,696,547—Gripping Members for Bonding—John M. Felton, Wellsburg, W. Va., and Clarence H. Verwohlt, St. Clairsville, Ohio, assignors to Wheeling Steel Corp., Wheeling, W. Va., a corporation of Delaware.

This patent relates to apparatus for gripping generally planar members for bonding. The apparatus includes a generally planar depressible supporting surface against which edges to be bonded together of the generally planar members are disposed in abutting relation. Specialized clamping means are present in the apparatus for securing the planar members in position and moving them in the apparatus.

2,697,126—Consumable Electrode and Procedure for Forming and Utilizing Consumable Electrodes—Schuyler A. Herres, Albany County, New York, assignor to Allegheny Ludlum Steel Corp., Brackenridge Pa., a corporation of Pennsylvania.

Herres's patent is on a longitudinally extending integral consumable electrode. This electrode is composed of a series of brittle longitudinal sticks of adhesively compacted hard-metal particles, which sticks are positioned in a longitudinal staggered and side-by-side abutting relationship. Continuous longitudinal weld beads secure longitudinally extending abutting edges of the sticks together in longitudinal progression along the electrode.

2,697,159—Welding Electrode and Coating and Method of Making the Same.—John W. Donahey, Drexel Hill, Pa., assignor to Foote Mineral Co., Philadelphia, Pa., a corporation of Pennsylvania.

About 7% to about 40% of a hydrophobic, water-insoluble glass is described in this patent for use in securing particles of welding flux ingredients to each other and to a welding electrode. This glass softens and flows under its own weight when heated to 1200° F for 5 min.

2,697,160—Direct Current Arc Welding—Clifton S. Williams, Pittsburgh, Pa., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

Williams' patent relates both to apparatus and method of arc welding work with a method comprising applying a straight polarity potential between an electrode and the work adequate to maintain an arc there-between. On such straight polarity potential, a periodical potential of relatively short duration and of polarity and magnitude such that a net potential of reverse polarity is impressed between the electrode and the work during the short duration of the periodicity of the periodic potential, is superimposed thereon.

2,697,768—Circular Seam Welding Apparatus—Leon Wolk, Rockville, Conn.

Wolk's patent relates to a resistance-type welding apparatus and it includes a stationary platen constituting one electrode of the apparatus and having a workpiece engaging surface. A rotary driven shaft is provided and means position the shaft on the axis are deposed substantially perpendicularly to the workpiece supporting surface. An arm is swingably connected to the shaft for swinging movement toward and away from the workpiece supporting surface, and a seam welding wheel is rotatably supported by the arm and a movable electrode is adapted to engage the side of the workpiece to travel in a circuitous path in engagement therewith. Thus a circular seam weld is provided on the workpiece.

2,697,769—Aluminum Sheathed Cable and Method of making—Floyd R. Carpenter, Piedmont, Calif., assignor to Kaiser Aluminum and Chemical

Corp., Oakland, Calif., a corporation of Delaware.

A process for continuously applying aluminum sheathing to insulated power cable is covered in this patent. The process comprises forming an open-seam tube from a metal strip and having a power cable positioned therein, passing such cable and tubing through high-frequency alternating electromagnetic field to induce alternating current voltage within the portion of the tubing located in such field. The opposed seam edges of the tubing are maintained in spaced relation during substantially the entire path of travel through the electromagnetic field and such seam edges are carried to be progressively brought into contact at a point adjacent the outer end of the magnetic field so that substantially all of the induced electric current in that section of the tubing concentrates and flows across the seam at such point of contact between the edges. The heat produced by such concentrated current flow fuses the seam edges together. Thereafter the fused edge portions of the tubing are reduced slightly in diameter to conform closely to the insulated cable.

2,697,770—Weld Rod—Otis R. Carpenter, Barberton, Ohio, assignor to the Babcock & Wilcox Co., New York, N. Y., a corporation of New Jersey.

A flux-coated metallic-arc welding rod for welding alloy steels of high corrosion resistance is disclosed in the patent. The weld rod core has a chromium content of from 20 to 30% and a nickel content of from 2 to 5%, while the balance principally is iron. A specialized composition flux coating is carried by the core.

2,697,771—Weld Rod and Method of Making—Harold Robinson, Somerville, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

Robinson's weld rod is for lead-bronze welding and the rod includes a core wire of an alloy of lead and tin surrounded by a plurality of strands of twisted copper wire. The core wire is formed with a surface contour conforming substantially to the original surface contour of the adjacent copper wire strands to eliminate substantially all voids in the rod and provide good thermal and electrical conductivity between the several strands of the rod.

2,697,772—Method of Making Material—Charles M. Kinghorn, Rye, N. Y., assignor to Kaiser Aluminum and Chemical Corp., Oakland, Calif., a corporation of Delaware.

This patent relates to applying aluminum sheathing to insulated cable wherein the aluminum strip material is progressively roll-formed into open seam tubing, such as is disclosed in Patent No. 2,697,769. The present patent relates to the step of feeding a nonconducting protective tape onto the cable as it is fed into the tubing so that the protective tape is positioned between the open seam and the cable so that the cable is protected from heat and flash produced during welding

2,697,774—Brazing Machine and Method—Fred Adler, Westbury, Ben L. Ehlin, Brooklyn, and Emil Kameny, Richmond Hill, N. Y., assignors to Standard Motor Products, Inc., Long Island City, N. Y., a corporation of New York.

This patent is on a machine for manufacturing small electric contacts of the type comprising a rivet shank having a head on top of which a contact disk is brazed. The machine includes a conveyer, and a series of spaced fixtures mounted upon the conveyer which is moved through a series of indexing stations at which stations various operations are provided in the way of inserting rivets into the fixtures, placing the contacts on the rivets, welding the contact disks to the rivet heads etc.

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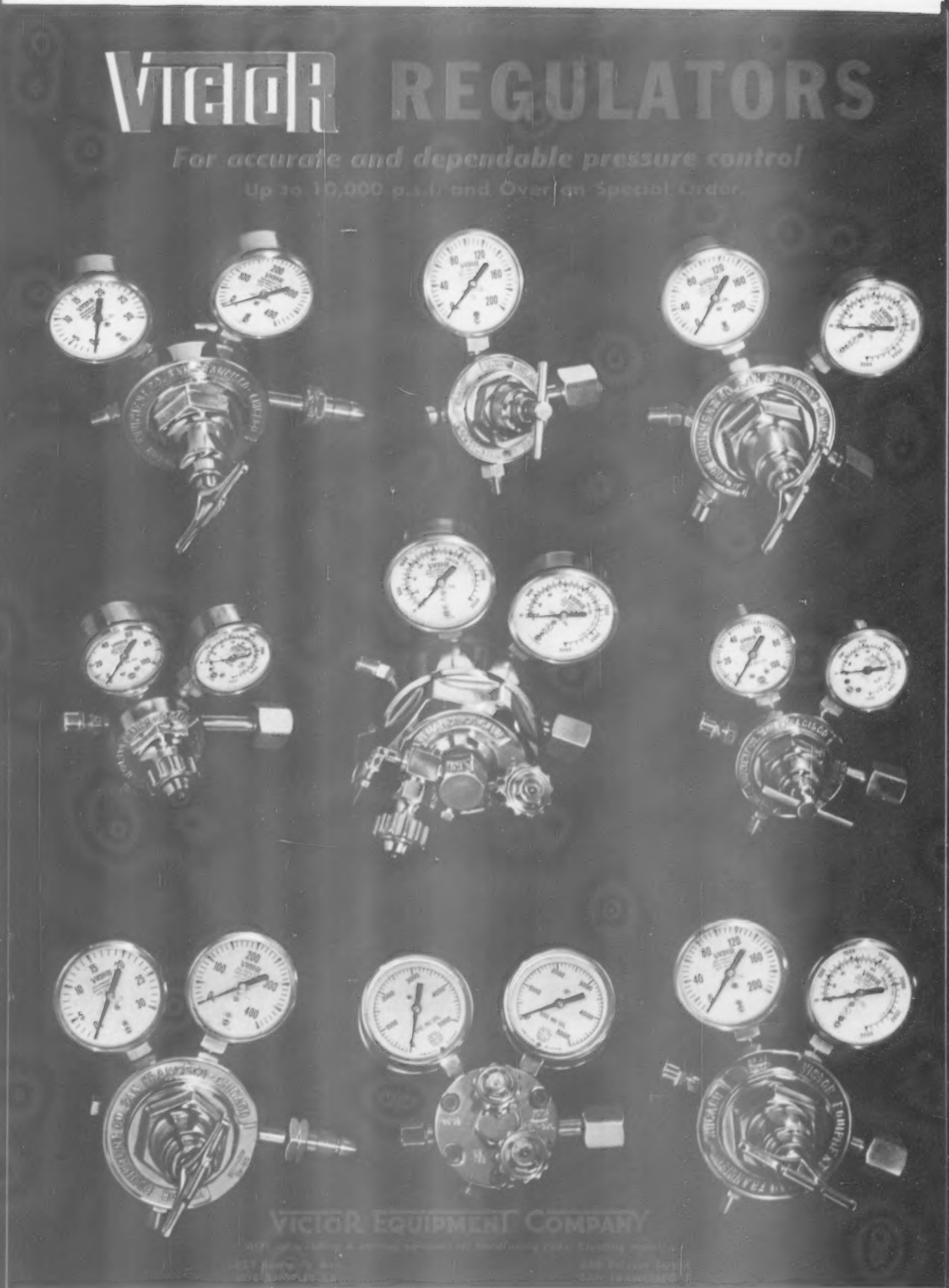
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SUPPLEMENT TO THE WELDING JOURNAL, FEBRUARY, 1955

BRAZING MOLYBDENUM FOR HIGH-TEMPERATURE SERVICE

Various brazing techniques which may be used to obtain good joints in molybdenum for high temperature service

BY M. I. JACOBSON AND D. C. MARTIN

ABSTRACT. The objective of this investigation was the development of methods of producing brazed joints in molybdenum that would have sufficient strength and ductility to be useful in engineering applications. The brazing methods that were investigated included vacuum brazing in an Inconel retort, oxy-acetylene torch brazing with a flux, induction brazing in vacuum and induction brazing in argon. Sixteen high-temperature brazing alloys that had melting points of 1800° F or higher were studied. The major factors that were determined were the ability of the alloy to wet molybdenum, the brazing techniques required to obtain good joints and the properties of brazed joints in commercial molybdenum sheet at room temperature and at a temperature of 1800° F. Induction brazing in an argon atmosphere was the most satisfactory brazing method from the standpoint of braze quality and practicability. Room-temperature strengths of brazed joints were generally low because of recrystallization of the base metal and because of the notch effects inherent in the joints. Short-time tension tests at 1800° F of joints induction brazed in argon showed that the best cobalt-base brazing alloy was Haynes Alloy 25 which produced a braze with a shear strength of 14,250 psi. The best noncobalt-base brazing alloy was Inconel, which produced a brazed joint with a shear strength of 18,800 psi. The 100-hr shear strength at 1800° F of joints induction brazed with Inconel was found to be 5000 psi, while the 100-hr shear strength of joints induction brazed with Haynes Alloy 25 was found to be 4500 psi.

M. I. Jacobson and D. C. Martin are with the Battelle Memorial Institute, Columbus, Ohio.

Presented at the AWS National Spring Meeting held in Buffalo, N. Y., May 4–7, 1954.

Introduction

This investigation was undertaken for the Air Research and Development Command with the objective of developing methods of producing brazed joints in molybdenum that would have sufficient strength and ductility to be useful in engineering applications. If such joints could be produced, molybdenum could be used as a construction material in certain types of heat engines. The use of molybdenum would permit higher operating temperatures than are now obtainable, with consequent increases in efficiency and power output. The difficulty encountered in the joining of molybdenum is at present one factor which restricts its use.

One of the most serious problems is the extreme brittleness of molybdenum welds. A review of available literature on the joining of molybdenum, including reports of other research conducted at Battelle, indicated that the brittleness is caused largely by the presence of impurities, both in the base metal and in the weld metal or weld line. It was found that the higher the purity of the base metal, the higher the ductility of the weldment. Another cause of brittleness in welds in commercial molybdenum is recrystallization of the base metal.

Brazing was therefore considered as a possible method of joining molybdenum without embrittlement of the base material. It was, of course, known that molybdenum could be brazed with several brazing materials. However, there was a considerable lack of information about the room-temperature and high-temperature properties of such brazed joints. Consequently, in this investigation a study of 16 high-temperature brazing alloys was made. The brazing alloys studied were chosen because they had a melting point of 1800° F or higher, and because it was hoped that they would have good strength at elevated temperatures. The major alloy groups included copper-base alloys, nickel-base alloys, cobalt-base alloys, and noble-metal alloys. The composition of the brazing alloys used in this investigation are given in Table 1. Many of these alloys were obtained from commercial sources, and were fabricated into foil for the brazing tests. The noble-metal alloys were prepared and fabricated at Battelle. The brazing methods that were used included vacuum brazing in an Inconel retort, oxy-acetylene brazing with a flux, induction brazing in vacuum and induction brazing in an argon atmosphere. The brazing procedure and test results obtained with these various methods are discussed in the following sections of this paper. Prior to this, however, the properties of as-received molybdenum sheet are described.

Properties of As-Received Molybdenum Sheet

Molybdenum sheet for this investigation was ordered from three manufacturers, each of whom supplied eight pieces of sheet

Table 1—Nominal Composition of High-Temperature Brazing Alloys

Alloy name	*Composition, %*	*Liquidus, ° F*
Super Nickel 826	70Cu - 30Ni	2240
Nickel	100 Ni	2650
Inconel	80Ni – 14Cr – 6Fe	2540
Chromel	90Ni – 10Cr	2550
Wall Colmonoy No 6	78Ni – 18Cr – 4B	1950
Monel	70Ni – 30Cu	2370
Hastelloy C	57Ni – 17Mo – 16Cr – 6Fe - 4W	2380
Haynes Stellite 21	60Co – 30Cr – 58i – 3Ni	2550
Haynes Alloy 25	55Co – 20Cr – 15W – 10Ni	2600
18–8 Stainless	18Cr – 8Ni – Bal Fe	2600
25–20 Stainless	25Cr – 20Ni – Bal Fe	2650
Kanthal A-1	70Fe – 25Cr – 5Al	2700
Palladium-Copper	60Pd – 40Cu	2200
Palladium-Nickel	53Pd - 47Ni	2200
Palladium-Silver	60Pd – 40Ag	2500
Silver-Platinum	70Ag – 30Pt	2200

$^1/_{16}$ x 4 x 18 in. In this paper, the sheet will be referred to as Type A, Type B and Type C molybdenum. Type A and Type B molybdenum sheets were fabricated from sintered powder compacts, while Type C sheet was fabricated from arc-cast carbon-deoxidized ingots.

Room-Temperature Ductility of the Base Metal

The ductility of the as-received sheet was determined by bend tests at room temperature. Tests results in Table 2 show that the sheet had good ductility parallel to the direction of rolling but that ductility was much lower in the transverse direction. Metallographic examination showed that all material was in the typical fibered condition, considered necessary for good bend ductility in commercial grades of sheet.

Recrystallization Study of $^1/_{16}$-In. Molybdenum Sheet

It was thought desirable to find out how long each base material could be heated at a given temperature before it recrystallized to the extent that ductility was impaired. Such information would be useful in determining the maximum allowable brazing times. The temperatures chosen were 2400, 2600 and 2800° F. Strips $^1/_2$ in. wide by $1^1/_2$ in. long of Types A, B and C $^1/_{16}$-in. molybdenum sheets were therefore heated by induction in vacuum at 2400° F for periods of 5, 10, 15 and 30 sec, and 1, 2, 3 and 5 min. The strips were then bend tested at room temperature at a strain rate of 0.011 in. per in. per sec. The results of the bend tests are plotted in Fig. 1, and a typical set of bend-test specimens is shown in Fig. 2. Test results showed that Type A sheet could be held at 2400° F for around 2 min; Type B around 1 min; and Type C around 30 sec before room-temperature ductility in the parallel direction was reduced to a value of about one-half that of the as-received sheet. However, at 5 min each material still exhibited some ductility. Photomicrographs of typical treated specimens are shown in Fig. 3. In general, the microstructures of these specimens could be correlated with the results obtained in the bend tests; that is, as the amount of recrystallization increased, the ductility decreased.

Similar tests were run at 2600 and 2800° F. However, at these high temperatures the mechanics of the heat-treating process were such that a considerable amount of scatter was produced in the data, and no conclusions could be drawn. The difficulties arose in attempting to attain the desired temperatures as rapidly as possible in order to simulate actual brazing conditions. The desired temperature was often exceeded, and it was thus difficult to maintain the correct time-temperature relationships.

The results of other investigations conducted at Battelle have shown that recrystallization alone is not sufficient to cause brittleness. Apparently, brittleness is caused by recrystallization combined with certain related grain-boundary phenomena. For the purpose of this report, the term "recrystallize" will be assumed to include both the recrystallization of the molybdenum and any associated effects.

Table 2—Room-Temperature Bend Ductility of As-Received $^1/_{16}$-In. Molybdenum Sheet

Type of molybdenum	*Direction**	*Deflection rate, ipm*	*Strain rate, in./in./sec*	*Bend angle, deg*
B	P	1	0.011	180
B	P	2	0.022	180
A	P	1	0.011	180
A	P	2	0.022	180
C	P	1	0.011	180
C	P	2	0.022	180
B	T	$^1/_2$	0.006	67
B	T	1	0.011	65
A	T	$^1/_2$	0.006	8
A	T	1	0.011	8
C	T	$^1/_2$	0.006	5
C	T	1	0.011	5

* P—Long axis of specimen parallel to direction of rolling T—Long axis of specimen transverse to direction of rolling

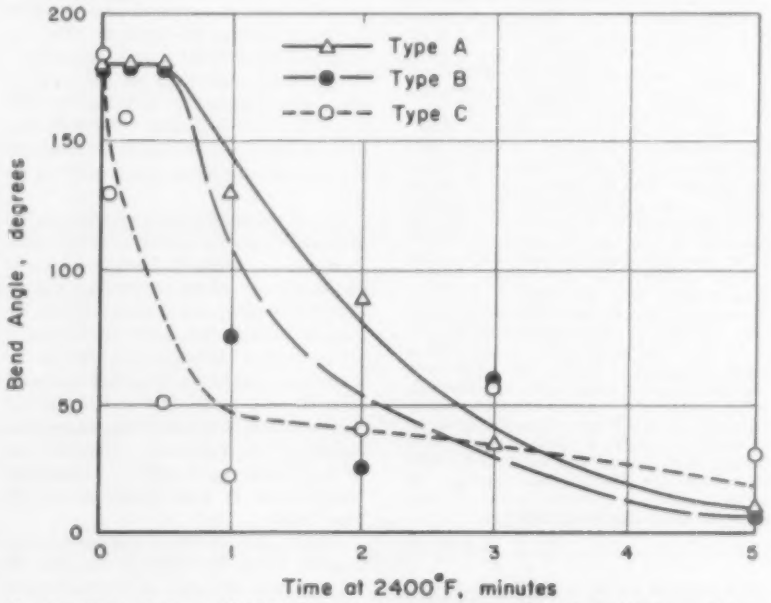


Fig. 1 Effect of time at 2400° F on the bend ductility of $^1/_{16}$-in. molybdenum sheet. Strain rate was 0.011 in./in./sec

Retort Brazing Tests

Material and Apparatus

The first brazing tests were made in an Inconel retort. The apparatus consisted essentially of a Globar-heated resistance furnace, a vacuum pump and an Inconel retort. The brazing tests were made with Type A and Type B molybdenum sheets.

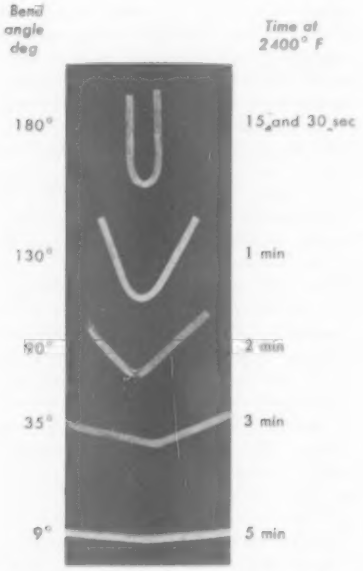


Fig. 2 Typical series of bend-test specimens of $^1/_{16}$-in. molybdenum sheet

Brazing Procedure

Prior to brazing, the molybdenum sheet was etched for 10 sec at 190° F in the following solution: 95 parts concentrated H_2SO_4 + 4.5 parts HF +0.5 part concentrated HNO_3 + 18.8 g/l Cr_2O_3. Both single- and double-lap-type joints were made from $^1/_{16}$- x 2-in. strips of sheet, as shown in Fig. 4. The specimens were assembled with strips of foil placed in the overlapping portions of the joints, clamped in jigs and placed in the retort. The retort was then sealed, evacuated to a pressure of less than 1 μ and placed in the furnace. Heating proceeded until the temperature in the retort was approximately 100 deg above the liquidus of the brazing alloy. After 10 min at temperature, the retort was removed from the furnace and allowed to cool to room

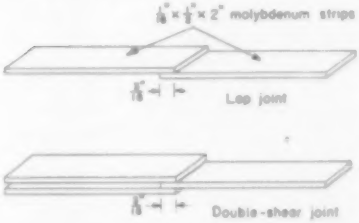


Fig. 4 Sketch of lap and double-shear specimens made with $^1/_{16}$-in. molybdenum sheet

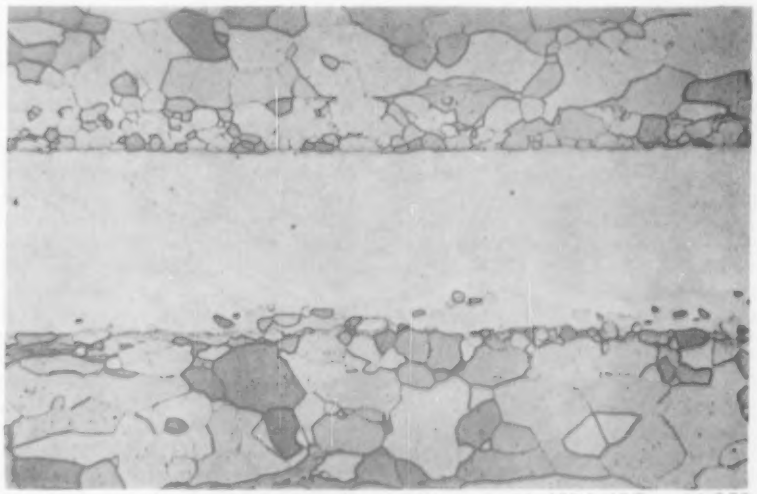


Fig. 5 Type A, $^1/_{16}$-in. molybdenum brazed in retort with 60Pd–40Cu. × 250

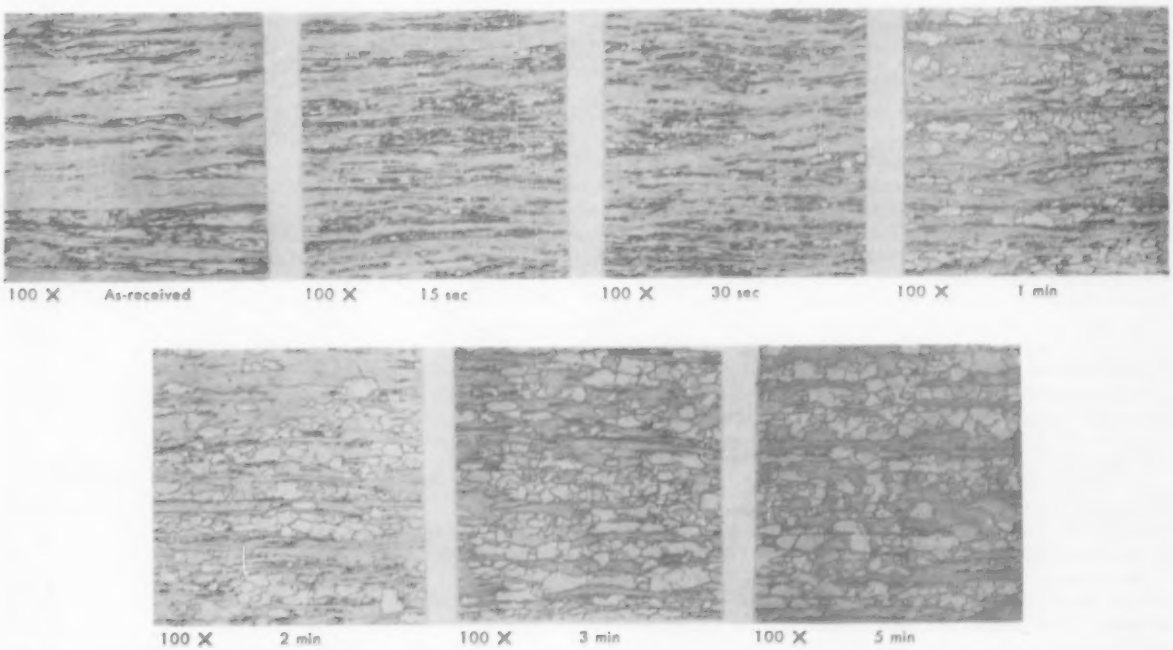


Fig. 3 Microstructure of $^1/_{16}$-in. Type A molybdenum sheet as-received and after various times at 2400° F

temperature before being opened. During heating, the pressure in the retort rose to 4 or 5 μ; however, this did not appear to have any effect on the molybdenum surfaces, as they were still clean and bright after being removed from the retort.

Results of Retort-Brazing Tests

Single-lap joints were brazed with 60Ni – 40Pd, Wall Colmonoy No. 6, Super Nickel 826, and 60Pd – 40Cu. Double-shear joints were made with 60 Pd – 40Cu. A typical photomicrograph of a brazed joint is shown in Fig. 5. The base metal is completely recrystallized because of the relatively long time cycle required to braze a joint in the retort.

The single-lap and double-shear specimens were tension tested at room temperature in a dynamometer at a speed of 0.150 ipm. Bending stresses were imposed on the single-lap joints during testing, which, combined with the fact that the base metal was recrystallized, caused the joints to fail in the base metal in a brittle manner at relatively low strengths, about 20,000 psi. It was therefore decided to standardize on double-shear-type specimens in which the testing loads were more evenly distributed. However, the double-shear-type tensile specimens also failed in a brittle manner in the center strip of base metal at around 23,000 psi. This was due to a combination of the base metal being recrystallized and the notch effect present in the double-shear-type joints.

Since the Inconel-retort apparatus was limited in temperature to brazing alloys that melted below 2300° F, and since the long brazing cycles resulted in complete recrystallization of the base metal, attention was turned to brazing methods that could produce higher temperatures and faster heating rates.

Oxy-acetylene-Brazing Tests

Development of a Flux for Oxy-acetylene Brazing

A few preliminary tests with brazing alloys that were previously found to wet molybdenum well indicated that for satisfactory oxy-acetylene brazes a flux would be required. No information was available on fluxes that would prevent or retard oxidation of the molybdenum at high temperatures. For testing various experimental fluxes, scrap $^1/_{16}$-in. molybdenum sheet was used. The fluxes were prepared in paste form and applied liberally to both sides of a strip of sheet. A $^1/_4$ x $^1/_2$ x 0.003-in. strip of brazing alloy was then placed on the top side of the sheet and covered with flux. The brazing alloys used had liquidus points from 1800 to 2500° F, which provided some idea of the temperatures attained in heating. A No. 4 torch tip was used for heating, with the flame adjusted so as to be slightly reducing. The specimens were heated until the brazing alloy melted and flowed. The flux was then removed by washing in hot water and wire brushing if necessary. The ease of flux removal and the protection from oxidation were noted.

In order to keep the molybdenum surfaces in the optimum condition for brazing, that is clean and free of oxides, it was decided that the flux should offer protection from oxidation from around 800° F up to the melting point of the brazing alloys (1800 to 2500° F). Several combinations of commercial fluxes were tried, as were combinations of commercial fluxes with additional fluorides and chlorides. In the majority of cases, it was found that the fluxes melted and flowed away from the hot zone before the brazing alloys melted.

After several trials, a flux was compounded that had a wide melting range and that gave fairly good protection up to around 2500° F. The composition of this flux was as follows: 10% boric acid, 6% AgCl, 10% LiCl, 27% Oxweld Brazo flux, 20% NaF and 27% CaF. In this flux mixture, boric acid (mp 350° F) gave low-temperature protection, AgCl (mp 840° F), LiCl (mp 1130° F), Oxweld Brazo-Flux (mp 950 to 1130° F) intermediate-temperature protection, and NaF (mp 1900° F) and CaF (mp 2480° F) high-temperature protection. Although the molybdenum appeared to be oxidized, metallographic examination showed little or no evidence of intergranular oxidation and no evidence of attack by the flux. The flux was difficult to remove and did not completely protect the molybdenum. However, it appeared to be satisfactory for the preparation of test specimens. Several double-shear tension specimens for room-temperature tests were therefore prepared with this flux, designated as Flux A.

Further work was done on developing an improved flux that would be easy to remove and that would provide molybdenum with good protection from oxidation. The experimental procedure was changed somewhat, in that the 60Pd – 40Ag alloy, which had a liquidus of 2500° F, was used to measure the degree of flow and wetting, in addition to being an indication of the temperature attained. It was found that the fluxes had better properties if mixed with alcohol rather than water to form a paste. The best flux combination developed was a 50-50 mixture of Eutector 189 and calcium fluoride, used in conjunction with specimens coated with Handy flux. This combination is designated as Flux B. Eutector 189 is a commercial borate-base brazing flux that is active in the range of 1400 to 2000° F. Handy Flux is a commercial borate-base silver-brazing flux that melts at 800° F and is active up to 1600° F. Calcium fluoride melts at 2480° F, so that Flux B is a wide melting-range flux that offers oxidation protection from around 800 to 2500 or 2600° F. Except for a small area immediately surrounding the solidified 60Pd – 40Ag alloy, specimens heated with Flux B were observed to be very clean and free of oxides, at least on the side on which the brazing alloy was placed. On the opposite side, that is the side heated directly by the torch, the degree of oxidation was somewhat greater. In either case, the oxide present could be largely removed by wire brushing and completely removed by an etching treatment. Flux B solidified as a white, granular mass that could be mostly washed off in hot water. The deposit remaining was easily removed by wire brushing.

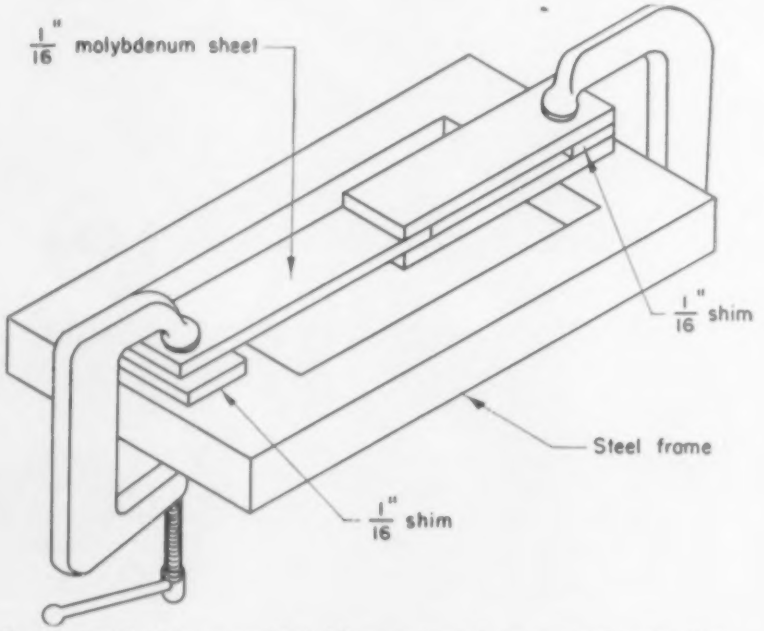


Fig. 6 Sketch of frame used in holding specimens for oxy-acetylene brazing

Oxy-acetylene brazing was also used to prepare joints for elevated-temperature testing. These joints were prepared with Flux B, using Inconel as the brazing alloy. The actual method of preparation and results obtained will be discussed in a subsequent section of this paper. However, it may be stated here that when Flux B was used to prepare an actual joint it was not so satisfactory as previous tests had indicated that it would be. In making the joints, the flux was heated directly by the torch and for longer periods of time than previously. The molybdenum surfaces were oxidized and the flux was very difficult to remove. Considerable work needs to be done on the development of a satisfactory flux, since oxy-acetylene brazing appears to be one of the more practical joining methods.

Oxy-acetylene-Brazing Procedure

Double-shear lap-type specimens were used to determine the room-temperature properties of oxy-acetylene brazes. Brazed joints were made in Types A, B and C molybdenum sheets. Strips of sheet measuring $^1/_2$ x 2 in. were cleaned prior to brazing in the etching solution described previously. The strips were assembled with a $^3/_{16}$-in. overlap, into which the brazing-alloy foil was placed, and clamped in the jig shown in Fig. 6. The brazing alloys that were used included 60Pd – 40Cu, 60Pd – 40Ag, Hastelloy C, Haynes Stellite 21, Haynes Alloy 25, 25–20 stainless, 18–8 stainless, Chromel, Monel and 70Cu – 30Ni. After being covered with generous amounts of Flux A, the joints were heated first on one side and then on the other side until the brazing alloy on each side had melted. Brazing times ranged from 25 to 50 sec. After brazing, the joints were washed in hot water and wire brushed to remove as much flux as possible.

Results of Oxy-acetylene-Brazing Tests

The oxy-acetylene-brazed joints were tested in tension at room temperature in a dynamometer at a rate of 0.150 ipm. The specimens generally failed in the center strip of base metal at ultimate tensile strengths ranging from 6400 to 80,000 psi, with the majority failing at 40,000 to 50,000 psi. The corresponding shear stresses on the brazes ranged from 1000 to 12,500 psi. However, as the specimens failed in the base metal, no measure of the true shear strengths of the brazes could be obtained. Failure in the base metal was believed to have been induced by a combination of the notch effect present at the joint fillet and the recrystallization of the molybdenum.

Almost all of the brazing alloys used in the oxy-acetylene-brazing tests flowed and wet well with the exception of the 25–20 and 18–8 stainless steels. A metallographic examination of several of the joints showed that good bonding had occurred. Photomicrographs of typical oxy-acetylene-brazed joints are shown in Figs. 7 and 8. As no spacers were used in making these joints, the thickness of brazing alloy present varied from joint to joint. Although this did not have any effect on test results, some type of spacer would probably be required in actual practice to maintain uniform joint thicknesses. The photomicrographs also show that base-metal recrystallization and grain growth were not so severe in the oxy-acetylene brazes as in the brazes made in the vacuum retort, in spite of the fact that the oxy-acetylene-brazed joints were made at higher temperatures.

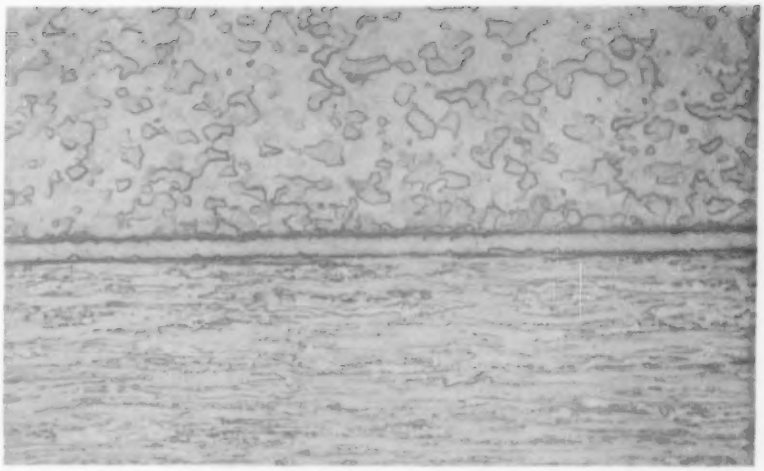


Fig. 7 Type A molybdenum oxy-acetylene brazed with 70Cu – 30Ni. × 100

Fig. 8 Type A molybdenum oxy-acetylene brazed with Hastelloy C. × 100

Induction-Brazing Tests

Since induction heating is a process that is used to attain high temperatures rapidly, it was considered as one method for brazing molybdenum. An extensive amount of work was done with induction brazing in preparing specimens for room-temperature and elevated-temperature tests, and in developing test specimens that would give the shear strengths of the brazed joints rather than the tensile strengths of the sheet. The induction-brazing apparatus and technique were modified several times during the course of the investigation to obtain as short a brazing cycle as possible. Power for the induction brazing was supplied by a 30-kw spark-gap frequency converter. Originally, brazing was done in vacuum in a Vycor tube, as shown schematically in Fig. 9. The modifications in this apparatus will be described subsequently along with the different test specimens used.

Double-Shear Tension Specimens

Double-shear-type tension specimens were prepared from Type B molybdenum sheet. After being cleaned by etching, as described previously, the specimens were assembled on a beryllium oxide block, as shown in Fig. 9. In addition to the brazing-alloy foil, small pieces of 0.003-in. molybdenum were placed in the over-

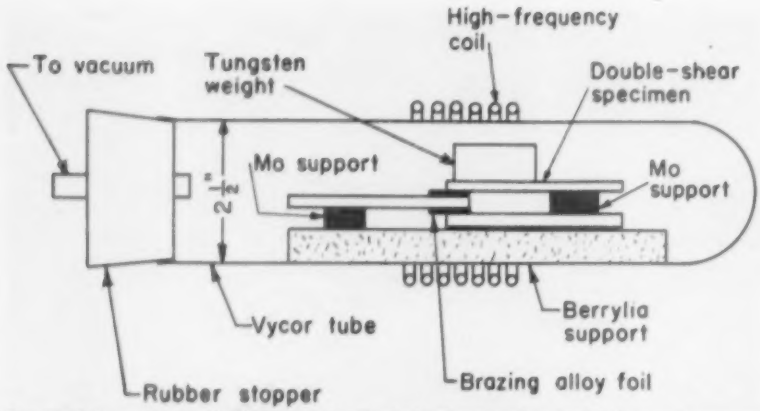


Fig. 9 Schematic sketch of apparatus for induction-brazing molybdenum in vacuum

lapping portions of the joint to act as spacers and provide a constant joint clearance. The joint assembly was placed in the Vycor tube and the system was evacuated to 0.2 μ. The induction unit was switched on, and the specimen was heated until the brazing alloy melted. The specimen was held an additional 5 sec to insure good flow and wetting. Brazes were made with Hastelloy C, Haynes Alloy 25, Haynes Stellite 21 and 60Pd–20Cu brazing alloys. The time for brazing varied from 25 to 60 sec. The time required to cool to below 1800° F was about 1 min. When tested in tension at room temperature, all of the joints failed in the center strip of base metal at ultimate tensile strengths ranging from 22,000 to 77,000 psi. Photomicrographs of typical induction-brazed joints are shown in Figs. 10 and 11, from which it may be seen that the joint thicknesses were nearly constant.

The tensile strengths developed in the sheet averaged 50,000 psi and were generally less than expected, apparently because of notch effects, recrystallization and small misalignments of the specimen in testing. Thus, it was not possible to determine the room-temperature shear strengths of the brazed joints by using double-shear joints.

When double-shear joints were induction brazed in vacuum, it was noted that the time required for the brazing alloy to melt was 25 to 60 sec. Such lengths of time are undesirable in the range 2400 to 2600° F, as they cause recrystallization of the molybdenum. Although this is not an important factor in testing, where it is desirable to test the strength of the brazed joint rather than the strength of the sheet, it is important from a practical standpoint. For example, it might be necessary to do a forming operation on a joint after brazing. In this case, it would be advantageous to have the molybdenum in the unrecrystallized and, therefore, more ductile condition. In order to try to reduce the time required for brazing, the induction-brazing apparatus was modified a number of times, the final result being shown in Fig. 12. A $^1/_2$-in. Vycor tube was substituted for the $2^1/_2$-in. tube, and a correspondingly smaller induction coil was used. An atmosphere of flowing argon was used rather than vacuum, with no adverse effects on the molybdenum surfaces. With this arrangement, it was possible to melt the brazing alloys in 5 to 6 sec, rather than in the 25 sec or longer previously required. Specimens were held at temperature for 5 sec after melting of the brazing alloy to insure good flow and wetting. The time required to cool to below 1800° F was reduced to 20 sec. In Fig. 12, a slotted-type tension specimen is shown in position for brazing. This type of specimen is described in the following section.

Slotted-Type Tension Specimens

The need for a test specimen that would cause brazed joints in sheet to fail under conditions approaching pure shear, and that would have no severe notch effects, resulted in the development of the so-called slotted tension specimens. These specimens were made from Type A sheet. They consisted of two pieces $^2/_3$ in. wide by 6 in. long machined as shown in Fig. 13. The specimens were assembled by wrapping 0.003-in. brazing-alloy foil around the end of the unslotted piece and slipping it into the $^1/_2$-in. slot. A room-temperature tension test was made with a specimen in-

Fig. 10 Type A, $^1/_{16}$-in. molybdenum induction brazed with Hastelloy C. X 100

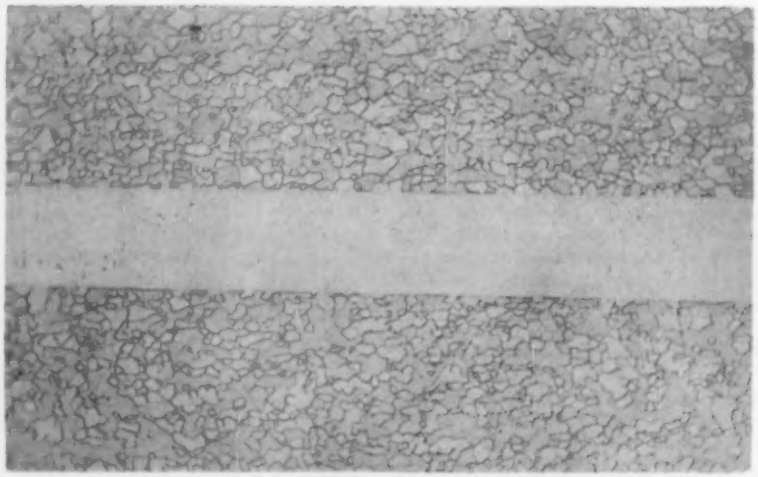


Fig. 11 Type A, $^1/_{16}$-in. molybdenum induction brazed with Haynes Alloy 25. X 100

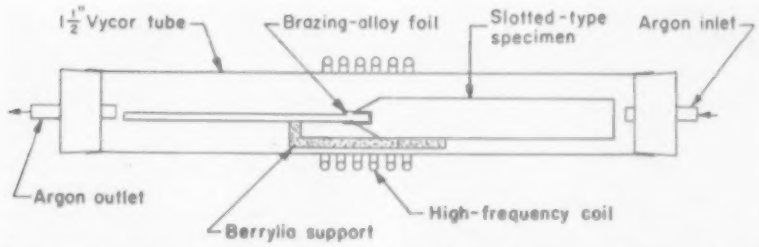


Fig. 12 Schematic sketch of apparatus for induction brazing slotted-type specimens in argon

duction brazed in argon, using Monel as the brazing alloy. The specimen failed in the base metal at an ultimate tensile strength of 35,000 psi. The test result and manner of fracture indicated that a notch effect was still present at room temperature.

It was believed that the notch effect might be reduced considerably at 1800° F. A slotted-type specimen was induction brazed in argon, using Type A sheet and Hastelloy C as the brazing alloy. The brazed specimen was loaded to failure in a vacuum creep furnace at 1800° F, merely to observe the manner of fracture. When the specimen was removed from the testing apparatus and examined, it was seen to have failed in shear. The unslotted piece had been pulled out of the slotted piece. Thus, since failure occurred by shear in the braze area, rather than by tension in the sheet, the actual shear strength of such brazed joints could be calculated.

It was decided to make short-time tensile tests at 1800° F on the slotted-type specimens brazed with several different alloys. On the basis of the test results, one cobalt-base and one noncobalt-base brazing alloy would be selected to braze specimens for 100-hr stress-rupture tests.

Short-Time Tension Tests at 1800° F

Ten slotted-type tension specimens were prepared for short-time tensile tests at 1800° F by induction brazing in an argon atmosphere. The molybdenum used was Type A sheet, which was chosen on the basis of its resistance to recrystallization. The brazing alloys were in the form of 0.003-in. foil. The brazed specimens were tested by placing them in the vacuum creep furnace, evacuating the furnace, heating to 1800° F, and loading the specimens until failure occurred. All specimens failed in the brazed joint, and from the load at failure the shear strengths were calculated. The results obtained are shown in Table 3.

Table 3—Results of Short-Time Tensile Tests at 1800° F

Brazing alloy	*Shear strength of braze, psi*	*Tensile on sheet, psi**
Inconel	18,800	25,000
Haynes Alloy 25	14,250	19,000
Monel	12,750	17,000
Hastelloy C	12,000	16,000
Haynes Stellite 21	12,000	16,000
53Pd–47Ni	9,400	12,500
70Ag–30Pt	7,200	10,500
60Pd–40Cu	6,400	8,500
60Pd–40Ag	4,500	5,000
Kanthal A-d	3,400	4,500

* Short-time tensile strength of unrecrystallized Type A sheet is 30,000 psi at 1800° F.

The above data suggest that the best noncobalt-base alloy was Inconel. The best cobalt-base alloy was Haynes Alloy

Table 4—Comparison of Short-Time Shear Strength of Brazed Joints and Ultimate Tensile Strength of Brazing Alloys

Alloy	*Condition*	*Ultimate tensile strength at 1800° F, psi*	*Shear strength of brazed joint in molybdenum at 1800° F, psi*
Inconel	Hot rolled	7,500	18,800
Monel	Hot rolled	5,000	12,750
Haynes Stellite 21	Cast	33,000	12,000
Haynes Alloy 25	Hot rolled	22,000	14,250
Hastelloy C	Hot rolled	18,200	12,000

Table 5—Results of Stress-Rupture Tests at 1800° F

Brazing alloy	*Brazing method*	*Shear stress on braze, psi*	*Tensile stress on sheet, psi*	*Rupture time, hr*
Haynes Alloy 25	Induction	14,250	19,000	*
		11,250	15,000	†
		7,500	19,000	9.4
		6,750	9,000	5.4
		4,500	6,000	147.0
Inconel	Induction	18,800	25,000	*
		11,300	15,000	0.5
		7,500	10,000	4.5
		5,600	7,500	88.4
Inconel	Oxy-acetylene	7,900	10,600	†
		5,600	7,500	4.2
		3,750	5,000	11.0

* Short-time tensile test
† Failed on loading (equivalent to short-time tensile test)

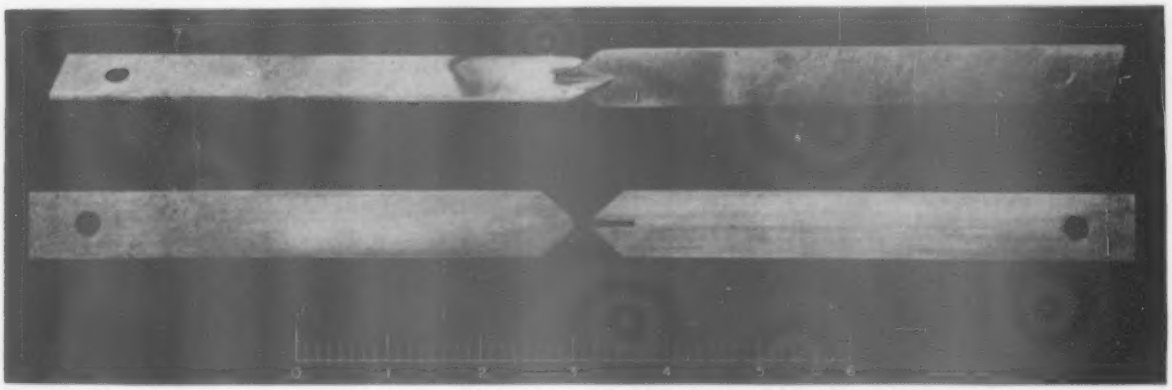


Fig. 13 Slotted-type specimens machined from 1/16-in. sheet. (Top) As-brazed; (bottom) before assembly

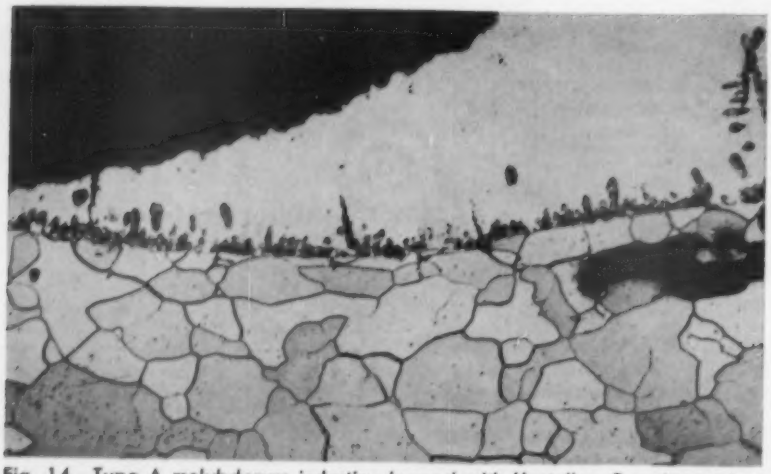


Fig. 14 Type A molybdenum induction brazed with Hastelloy C and tested at 1800° F. X 250

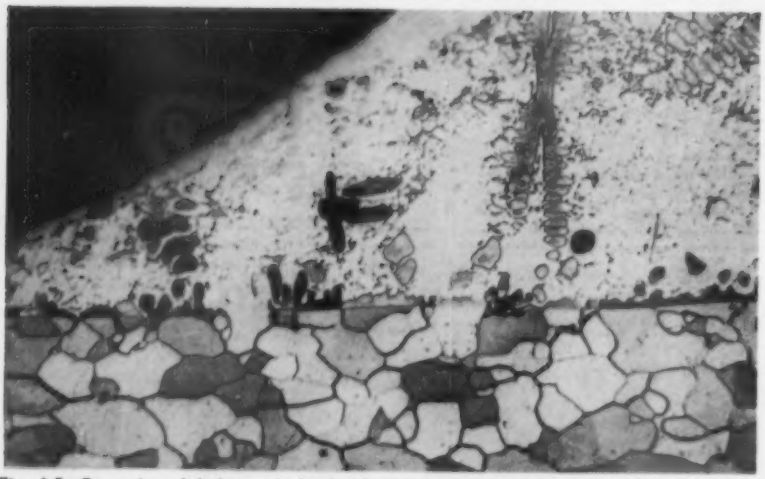


Fig. 15 Type A molybdenum induction brazed with Monel and tested at 1800° F. X 250

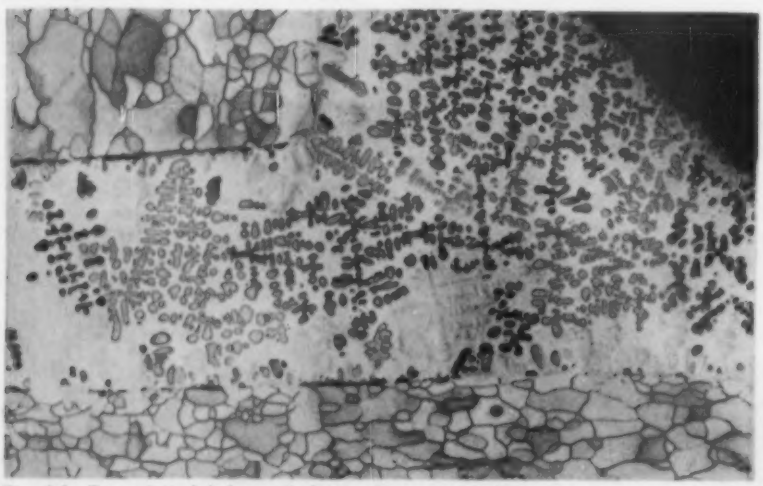


Fig. 16 Type A molybdenum induction brazed with Inconel, as-brazed. X 100

25. Wherever data of other investigators were available, comparisons were made between the short-time tensile strengths of the brazed molybdenum joints and the short-time tensile strengths at 1800° F of the brazing alloys themselves. The comparison is shown in Table 4.

In the case of Inconel and Monel, the shear strengths of the brazes were considerably higher than the tensile strengths of wrought sheet, while for Haynes Stellite 21, Haynes Alloy 25 and Hastelloy C the shear strengths of the brazed joints were lower. A metallographic examination was made of all of the brazed specimens after they had been tested. For Inconel and Monel, there was evidence of considerable diffusion of molybdenum into the brazing alloy, which might explain the increase in elevated-temperature strength of the brazed joint as compared with the strength of the alloy alone. With Haynes Stellite 21, Haynes Alloy 25 and Hastelloy C, the lower strengths of the brazed joints may be due to the formation of a brittle compound in the bond area. Photomicrographs of the bond area in several of the fractured tension specimens are shown in Figs. 14 through 17.

Stress-Rupture Tests at 1800° F

On the basis of the results obtained in the short-time tensile tests, Inconel and Haynes Alloy 25 were selected as the brazing alloys to be used in making 100-hr stress-rupture tests. The base metal was $^1/_{16}$-in. Type A sheet. Four slotted-type specimens for each alloy were induction brazed in argon, using the apparatus shown in Fig. 15. The time required for the Inconel to become molten was 6 sec, and for the Haynes Alloy, 5 sec. After the brazing alloy had melted, the specimens were held at temperature for 5 additional seconds to insure good flow and wetting. Oxy-acetylene brazing was also used to prepare four slotted-type tension specimens, using Inconel as the brazing alloy and Flux B. These specimens required approximately 1 min to braze.

In making the stress-rupture tests, the specimens were placed in the vacuum creep furnace, heated to 1800° F, and loaded to preselected stress levels that were below the short-time shear strengths of the brazes. The specimens were held under these conditions until failure occurred. All failures occurred in the brazing alloy at the strengths shown in Table 5.

Figure 18 shows the stress-rupture curves drawn from the above data. The 100-hr strength of joints brazed with Haynes Alloy 25 was found to be around 4500 psi, which compares with the 100-hr strength of 10,000 psi for Type A molybdenum sheet and 10,500 psi for wrought Haynes Alloy 25 sheet. The 100-hr strength of induction-brazed Inconel joints was about 5000 psi, while the figure for oxy-acetylene-brazed joints was approximately 2500 psi. The induction-brazed

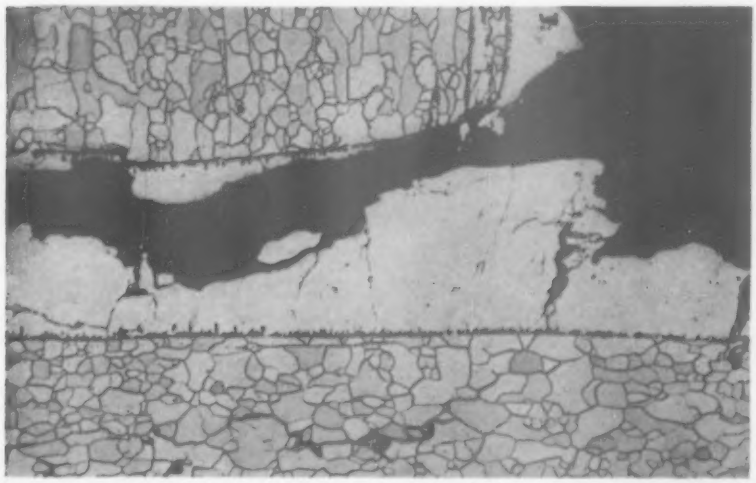


Fig. 17 Type A molybdenum induction brazed with Haynes Alloy 25 and tested at 1800° F. X 100

joints thus had a 100-hr shear strength that was approximately 50% of the 100-hr stress-rupture strength of wrought molybdenum sheet at 1800° F.

Effect of Brazing Cycle on Microstructure and Brazing-Alloy Composition

As mentioned in the previous section, the slotted-type tension specimens brazed with Inconel and Haynes Alloy 25 were prepared by heating until the brazing alloy melted (5 or 6 sec), and then holding for 5 sec to insure good flow and wetting by the brazing alloy. The temperatures attained were approximately 2700° F, and, although the brazing time was very short, metallographic examination showed that the base metal had nevertheless recrystallized 100%. This suggested that the 5-sec holding time might be too long. Four slotted-type specimens were therefore induction brazed in argon, using Type A sheet and Inconel as the brazing alloy. The specimens were heated until the Inconel melted, which required 6 sec, and were then held at the melting point for 0, 1, 2 and 3 sec. Photomicrographs of the specimens are shown in Fig. 19. The degree of recrystallization of the base metal was found to range from about 20% for the 0-sec specimen to 100% for the 2- and 3-sec specimens. However, the recrystallized grain structures were relatively fine, indicating that the base metal might have good ductility. In examining the Inconel in the joints, it may be seen that for the 0- and 1-sec holding times, no second phase is present. However, for the 2- and 3-sec holding times, a second phase is present in the Inconel. This is also shown in Fig. 16, which is an induction brazed joint in Type A molybdenum in which the Inconel was held molten for 5 sec. It is believed that this second phase is caused by molybdenum diffusing into the Inconel during brazing. This might explain the observation that the short-time tensile strength of rolled Inconel sheet at 1800° F is 7500 psi, while the short-time shear strength of a joint brazed with Inconel is 18,800 psi at the same temperature. Further evidences of diffusion of molybdenum into the Inconel were obtained by making tests to determine the remelt temperature of joints brazed with Inconel and by measuring the hardnesses of the Inconel. The procedure for determining remelt temperatures was to prepare a single-lap joint by induction brazing, using a holding time of 5 sec. This single-lap joint was suspended vertically in an induction heating apparatus which is used to determine the melting point of metals and alloys. The joint was heated until the brazing alloy became molten and the two pieces separated. This occurred at a temperature of approximately 3100° F, as compared with the melting point of 2540° F for Inconel alone.

Vickers hardness readings were made on the Inconel in the joints held at brazing temperature for 0, 1, 2, 3 and 5 sec. The hardness of the Inconel increased from 330 Vhn for the 0-sec specimen to 667 Vhn for the 5-sec specimen. It is therefore apparent that joints brazed with Inconel owe their high strength to the diffusion or alloying of molybdenum and Inconel. Thus, although shorter holding times will reduce the degree of recrystallization of the base metal, a 5-sec holding time is apparently required to get high strength, at least in the case of Inconel.

Fields for Further Study

It has been demonstrated that molybdenum can be joined readily by furnace brazing in vacuum, oxy-acetylene brazing with a flux and induction brazing in vacuum or argon. From the standpoint

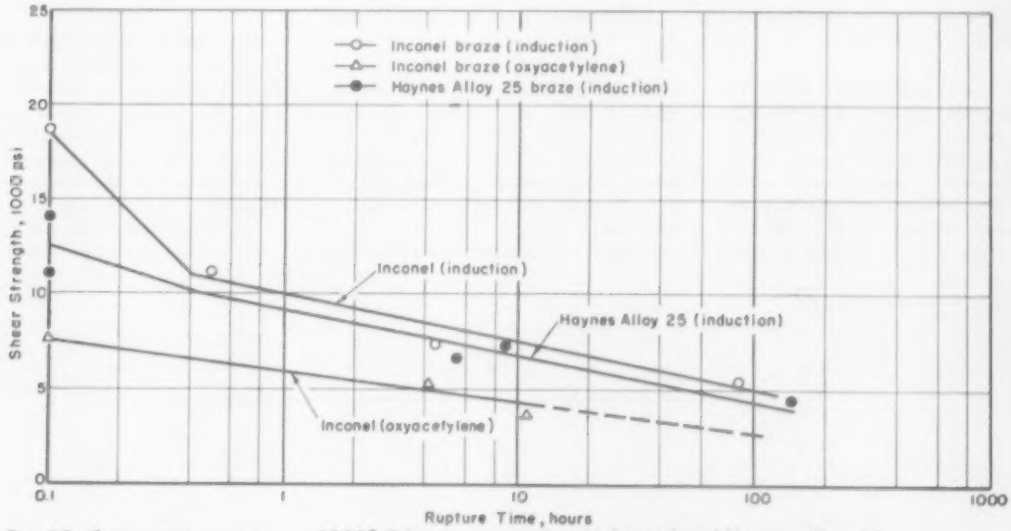


Fig. 18 Stress-rupture curves at 1800° F for brazes made with Inconel and Haynes Alloy 25

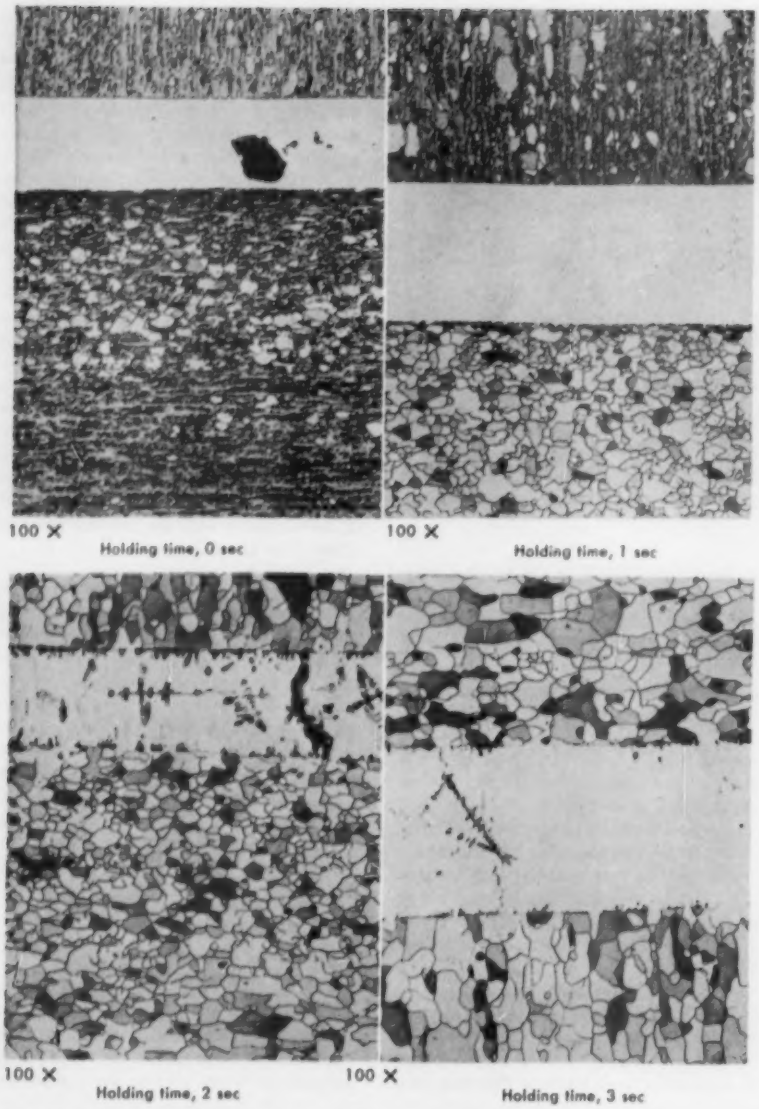


Fig. 19 The effect of holding time on Type A molybdenum joints induction brazed with Inconel

of quality and practicability, induction brazing in argon appeared to be the most suitable brazing method. It must be pointed out, however, that the use of induction brazing in actual practice would be limited by the size and shape of the piece being formed. With induction brazing, joints were made that had excellent strength and stress-rupture properties at 1800° F. However, the creep properties of the brazed joints were not determined, and this information is necessary before brazed molybdenum can be considered for elevated-temperature structures.

Strength tests in this investigation were limited to 1800° F. Further tests should be made at higher temperatures, such as 2000° F.

A testing problem in the evaluation of brazed joints is the difficulty in measuring the ductility of the brazing material itself. Although bend tests can be made on the base metal immediately adjacent to the brazing alloy, no actual measurements of brazing-alloy ductility are possible. The development of some method or type of specimen for measuring ductility in brazed joints would be helpful.

In brazing molybdenum, it might be desirable for certain applications to keep recrystallization of the base metal at a minimum in order to maintain good ductility. With commercial grades of molybdenum, it was practically impossible to prevent recrystallization at the high brazing temperatures used, even though the time at temperature was only a few seconds. One method of preventing, or retarding, recrystallization would be to develop a brazing alloy with a melting point of 2400° F or less that would have high-temperature properties equal to or better than Inconel or Haynes Alloy 25. The alloy should be capable of being rolled into brazing foil, and should react with molybdenum in a manner similar to that of Inconel. Another method of preventing recrystallization would be to use a molybdenum-alloy base metal having good resistance to recrystallization. Experimental alloys of this type are already being investigated, and molybdenum-titanium alloys with recrystallization temperatures of 2600° F can be obtained commercially.

Since oxy-acetylene equipment is relatively inexpensive and readily available, it might be desirable to investigate oxy-acetylene brazing further. The need is for a flux that will protect molybdenum up to around 2600° F and that can be removed easily after brazing.

Acknowledgment

The authors want to take this opportunity to thank numerous members of the Battelle Institute for their aid and advice. We wish especially to thank C. B. Voldrich and H. B. Goodwin for their interest and helpful suggestions. Acknowledgment is also due I. Perlmutter, Major M. J. Whitman and R. E. Bowman, of the Wright-Patterson Air Force Base Materials Laboratory for their help.

SIGMA PHASE IN AUSTENITIC STAINLESS STEEL WELDMENTS

Occurrence of sigma phase and its effects on tensile-impact properties of austenitic stainless steel weldments

BY O. H. HENRY, M. A. CORDOVI AND G. J. FISCHER

ABSTRACT. The investigation described in this thesis was undertaken for the purpose of determining the effect of sigma phase on the tensile-impact properties of aged austenitic stainless steel weldments in unnotched and notched conditions. The specific effect of notching weldments in the base metal, heat-affected zone or weld was also determined. The materials selected for this study included AISI Types 304, 310, 321 and 347 austenitic stainless steels, which were subjected to temperatures of 1200, 1350 and 1550° F for a minimum of 1500 hr. All alloys were tested prior to aging at the above temperatures to establish a basis of comparison when in the embrittled state. The effect of a solution anneal of 1950° F after aging at 1550° F was also determined.

As a result of this investigation, it was found that unnotched and notched AISI Type 310 stainless steel weldments were seriously embrittled at aging temperatures of 1200, 1350 and 1550° F, while AISI Types 321 and 347 weldments were embrittled at the lower aging temperatures of 1200 and 1350° F. The notch sensitivity of welds of the latter types increased at 1550° F. Notched weld component results indicated that welds were more notch sensitive than base metal or heat-affected zones in all alloys. The precipitation of sigma phase was associated with decrease in tensile-impact properties. It was observed that a solution anneal of 1950° F was effective in restoring the toughness of materials embrittled at 1550° F.

Materials and Procedures

Composition and Heat Treatment

The heat treating schedule used represents one of the most important phases of this investigation. A wide enough range of temperatures was chosen to make certain that all of the materials used would be exposed to the most favorable conditions for sigma formation. Also the time at each temperature level had to be long enough to produce sigma.

The chemical composition of the plate and bar material used in this study is shown in Table 1.

All of the above materials were obtained from commercial heats of electric furnace steel. The plate material was formed from tubing split longitudinally and flattened, while the bar stock (3/4 in. diam) was rerolled from 3-in. tube billets. Both bar and plate stock were received in the hot-rolled condition.

A detailed summary of materials, number of samples, post weld heat treating schedule and code system is shown in Table 2.*

During the aging treatment of alloys in Group II at 1200° F, a furnace failure occurred after the samples were at temperature for several weeks. As a result, these test pieces were overheated and could not be used in such a condition in this investigation. The Babcock & Wilcox Co. graciously offered to replace the ruined test bars with welded material of similar composition. The composition of these replacement bars is shown in Table 3.

O. H. Henry and M. A. Cordovi Professor and Adjunct Professor, respectively Brooklyn Polytechnic Institute. G. J. Fischer is Director, Metallurgy Dept., Sam Tour & Co.

Abstract of a thesis by George J. Fischer submitted for the Degree of Master of Metallurgical Engineering.

* See Section on "Preparation and Welding Procedure" for preliminary treatment.

Table 1

Type→	*304*	*321*	*347*	*310*	*321*	*347*
Form→	*Bar*	*Bar*	*Bar*	*Plate*	*Plate*	*Plate*
Size→	*3/4 in. diam*	*3/4 in. diam*	*3/4 in. diam*	*12 x 1½ x 1/2 in.*	*6 x 1⅜ x 5/16 in.*	*6 x 16 x 5/8 in.*
C	0.076	0.060	0.071	0.060	0.070	0.068
Mn	1.81	1.77	1.75	1.66	1.80	1.75
Si	0.39	0.50	0.22	0.30	0.51	0.43
Cr	18.54	17.88	17.63	25.24	17.37	18.00
Ni	10.04	12.88	12.54	20.86	12.68	12.40
Mo	0.18	0.08	0.13	0.17	0.15	0.11
Cb	...	...	0.86	...	...	0.90
Ti	...	0.42	...	...	0.53	...
Cu	0.12	0.12	0.07	0.15	0.18	0.08

Table 2

Group I—Initial heat treatment before aging

Type	*Treatment*	*Remarks*
304	1850° F, 1/2 hr.; oil quenched	Bar stock
321	1850° F, 1/2 hr.; oil quenched	Bar stock
321	1850° F, 1/2 hr.; fast furnace cooled	Welded
347	1850° F, 1/2 hr.; fast furnace cooled	Welded
310	No treatment	Welded

Group II—Samples aged at 1200° F for 1512 hr
Group III—Samples aged at 1350° F for 2120 hr
Group IV—Samples aged at 1550° F for 1500 hr
Group V—Samples aged at 1550° F for 1500 hr, followed by a resolution anneal at 1950° F for 1/2 hr; then water quenched
NOTE: Before aging at various temperatures noted, all samples in Groups II, III, IV and V were heat treated in accordance with the schedule followed for Group I.

Table 3

Type	*304*	*310*	*321*	*347*
Carbon	0.05	0.12	0.054	0.07
Manganese	0.48	1.74	1.72	1.41
Silicon	0.53	0.83	0.42	0.48
Chromium	19.61	25.04	18.44	18.21
Nickel	9.20	18.88	12.44	10.10
Molybdenum	0.03	0.06	0.22	...
Columbium	...	...	...	0.77
Titanium	...	...	0.32	...
Tantalum	...	...	...	0.04

Welding Procedure

All of the stainless steel material tested in this investigation was furnished by the Babcock & Wilcox Co., Tubular Products Division, Beaver Falls, Pa. The material was supplied in both plate and bar form, the former for the purpose of preparing specimens containing welds.

The plate material was subsequently welded by the M. W. Kellogg Co., Jersey City, N. J. A description of the sequence of operations used by Kellogg for the preparation and welding of the material is given below.

Preparation and Welding Procedure

1. All plates welded were cut to approximately a 3 in. width with the direction of rolling.

2. Plates were then solution treated at 1950° F for one-half hour, followed by oil quenching.

3. Plates were flattened, beveled on one edge of each set at 45 deg, other edge square.

4. Plates were welded in a flat position with light beads. Backing was removed after second bead. Assembly was then tacked to a heavy carbon steel plate to minimize distortion. Precautions were taken to keep the plates cold.

5. A Type 347 chill strip backing was provided for Types 321 and 347 plate, while a laminated chill strip containing three (spot-welded) thicknesses of 1/16-in. thick Type 310 strip was used as backing for the 310 plates. As noted above, all chill strips were removed after the second bead.

6. The following welding rods (with heat numbers) were used for welding the plate material.

Plate type	*Welding electrode*
310	Arcos lime-coated Type 310 1/8-in. diam rod—no heat number 5/32-in. diam rod—E2350, U310, F15122
321 and 347	Arcos lime-coated Type 347 1/8-in. diam rod—D2489, T308, F55117 5/32-in. diam rod—E2241, U308, F105013

The welding sequence used for Types 310 and 321 is shown below.

Bead No.	*Size wire, in.*	*Amp*	*V*	*Interpass temperature, ° F*
1	1/8	80	22	100
2	1/8	80	22	100
3	5/32	110–115	22	100
4	5/32	110–115	22	100
5 and 6	5/32	110–115	22	100
7 and 8	5/32	110–115	22	100

The welding sequence for Type 347 plate was as follows:

Bead No.	*Size wire, in.*	*Amp*	*V*	*Interpass temperature, ° F*
1	1/8	80	22	100
2	1/8	80	22	100
3	5/32	110–115	22	100
4	5/32	110–115	22	100
5 and 6	5/32	110–115	22	100
7 and 8	5/32	110–115	22	100
9 and 10	5/32	110–115	22	100

NOTE: Materials in both above cases were water quenched after each layer.

7. After welding, the reinforcement was ground flush with the plate.

8. All welds were X-rayed and zygloed on both sides to detect any possible defects. All welds were found to be sound.

9. Specimens were then cut from the welded plate. Plates were welded perpendicular to rolling direction of plate material. Samples were cut parallel to direction of rolling to insure that the tests would be conducted with the tensile load parallel to the rolling direction.

Welding Procedure of Replacement Bars

As noted in the previous section on chemical composition, a separate group of bars was prepared for replacement of material overheated at 1200° F. The welding procedure used for these replacement specimens was identical to that used by the M. W. Kellogg Co. Since Arcos HCN (25Cr – 20Ni) electrode material was not available, the Babcock & Wilcox Co. 25Cr – 20Ni welding rod was used as a substitute material.

Test Specimens

Tensile-impact test specimens were prepared from both plate and bar stock by machining to the dimen-

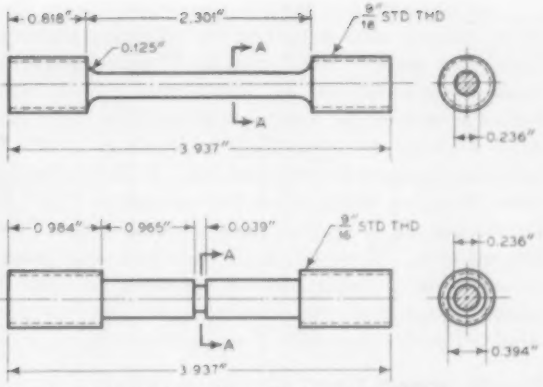


Fig. 1 Test specimen (unnotched and notched)

sions shown in Fig. 1. These dimensions are specified by the American Society for Testing Materials as Type V and Type U in the appendix to Standard E23–47T for Impact Testing of Metallic Materials. As can be seen from Fig. 1 Type V was utilized to determine the toughness of unnotched base and weld metal. A photograph of two unnotched test samples, one from bar stock and the other from welded plate, is shown in Fig. 2. Type U specimen in Fig. 3 was used to determine the relative notch sensitivities of the base metal, heat-affected zone and weld metal. The position of the weld in regard to the notch was shifted so that the notch was always at the center of the test bar.

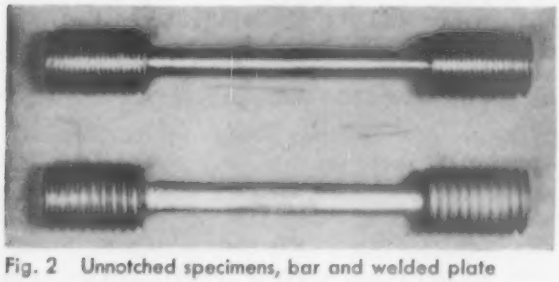


Fig. 2 Unnotched specimens, bar and welded plate

This is shown in Fig. 3 where three Type U specimens are shown notched individually in the weld metal, heat-affected zone and base metal, respectively. It will be noted that one plate was beveled and the other square. This was necessary since the squared part of the weld junction provided a continuous heat-affected zone perpendicular to the applied load which could be notched $^1/_{32}$ in. from the weld.

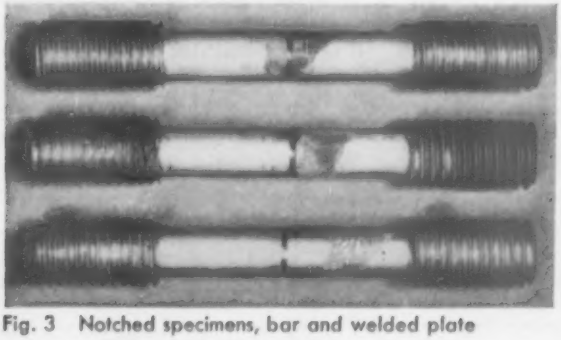


Fig. 3 Notched specimens, bar and welded plate

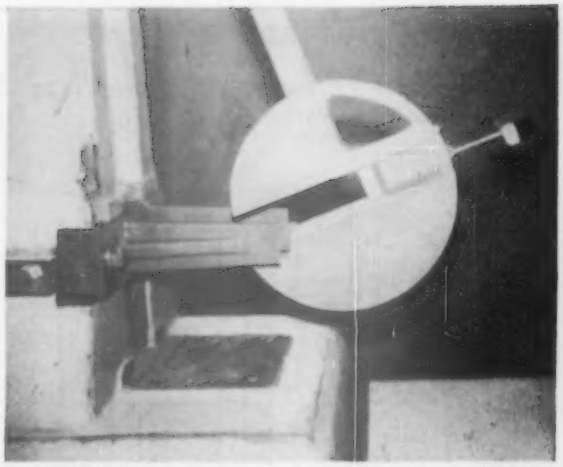


Fig. 4 Testing machine

Test Method

The tensile-impact tests described in this investigation were conducted with the aid of a Riehle combination Izod, Charpy and tensile-impact testing machine of 220 ft-lb capacity. In order to test specimens in tensile-impact, the Charpy and Izod anvils had to be removed and replaced with two anvils of equal length as shown in Fig. 4. One end of the tensile-impact sample (threaded at both ends) is screwed into the rear of the pendulum bob while the other end is screwed into the impact crosshead. As the pendulum swings from its initial position through the lowest point in its arc, the crosshead strikes the anvils causing the entire inertia of the pendulum to be exerted axially upon the specimen.

All tests were conducted at room temperature.

Metallography

The etchants used to identify sigma by metallographic examination include glyceregia, Vilella's reagent (picric and hydrochloric acids in alcohol), and 10 *N* potassium hydroxide used electrolytically.

In this investigation, glyceregia was used chiefly to etch Type 310 steel, while Vilella's reagent was used to etch Types 321 and 347. It was found that the KOH etchant was very effective in revealing sigma in Types 310 and 321 steel.

A compilation of the microstructural constituents observed in each of the samples examined is shown in Table 4.

From the microstructural survey, it was noted that sigma phase formed in Type 310 weld and base metal after aging at 1200, 1350 and 1550° F. Evidence of sigma phase was found in base and weld of Type 321 steel after aging at 1200 and 1350° F and only in the weld metal after aging at 1550° F. In Type 347 material, sigma phase was precipitated in base and weld metal after aging at 1200, 1350 and 1550° F. Carbides were precipitated in Type 304 after aging at 1200, 1350 and 1550° F. Solution annealing at 1950° F redissolved the carbide precipitate.

Table 4

Location of sample	Treatment	Structure*
	Type 310	
Weld	Anneal	A + C
Weld junction	Anneal	A + C
Base	Anneal	A
Weld	1200° F	A + S
Base	1200° F	A + S
Weld	1350° F	A + S + C
Base	1350° F	A + S + C
Weld	1550° F	A + S + C
Weld junction	1550° F	A + S + C
Base	1550° F	A + S + C
Weld	1550 + 1950° F	A + S′ + C′
Weld junction	1550 + 1950° F	A + S′ + C′
Base	1550 + 1950° F	A + S′ + C′
	Type 321	
Weld	Anneal	A + C
Base	1200° F	A + S + C
Weld	1200° F	A + S + C
Weld	1350° F	A + S + C
Weld	1350° F	A + S + C
Base	1350° F	A + S + C
Weld	1550° F	A + S + C
Base	1550° F	A + C
Weld	1550 + 1950° F	A + S′ + C′
Base	1550 + 1950° F	A + C
	Type 347	
Weld	Anneal	A + C
Base	1200° F	A + S + C
Weld	1200° F	A + S + C
Base	1350° F	A + S + C
Weld	1350° F	A + S + C
Base	1550° F	A + C
Weld	1550° F	A + S + C
Base	1550 + 1950° F	A + C
Weld	1550 + 1950° F	A + C
	Type 304	
Base	Anneal	A
Base	1200° F	A + C
Base	1350° F	A + C
Base	1550° F	A + C
Base	1550 + 1950° F	A
	Type 321	
Base	Anneal	A + C
Base	1200° F	A + C
Base	1350° F	A + S + C
Base	1550° F	A + C
Base	1550 + 1950° F	A + C

* A = austenite, S = sigma, C = carbide, S′ = partially dissolved sigma, C′ = partially dissolved carbide.

Magne-Gage Tests

A determination of the ferrite content of welds and base metals under all of the various heat treated conditions was included in this study. The method used was dependent on magnetic measurements made with the aid of an Aminco-Brenner Magne-Gage. This instrument is used to determine the thickness of nonmagnetic coatings on steel, nickel coatings on steel and nickel coatings on nonmagnetic metals by measuring the relative ferromagnetism of magnetic materials.

The results of these Magne-Gage tests are shown in Table 5.

From the results of the microstructural survey and ferrite content determination, the following observations were made. The formation of sigma phase in welds of Types 321 and 347 transformed initially from ferrite present in the welds in the annealed condition. After solution annealing these materials at 1950° F, following the aging treatment at 1550° F, ferrite formed from the sigma phase which precipitated at 1550° F. Ferrite was not detected in the original as-welded Type 310 material. However, both base and weld metal contained ferrite after solution annealing at 1950° F which formed from the massive sigma particles precipitated during the 1550° F aging treatment.

Tensile-Impact Tests

The experimental results and calculated data obtained from the tensile impact tests are shown in Figs. 5 and 6. No elongation or reduction in area data were recorded for notched bars since these properties would be practically zero in all conditions. Some specimens required two blows before rupturing; the material under test absorbed the full 220 ft-lb of the first blow and required an additional amount of energy of (*x*) ft-lb to rupture.

Discussion of Results

The average values of results for unnotched bars are depicted graphically in Fig. 5. Similarly, the results for notched bars are presented in bar graph form in Fig. 6. A study of these results indicates certain trends which are briefly discussed below.

1. AISI Type 304 (18Cr – 8Ni)

This material exhibited satisfactory toughness and ductility both in the unnotched and notched conditions, although some evidence of notch sensitivity was apparent in the latter case. This is not unexpected in view of the fact that the temperature range used represents the region where carbide precipitation occurs in this material. No evidence of sigma formation was detected.

2. AISI Type 321 (18Cr – 8Ni Ti)

No serious embrittlement occurred in the *unnotched* bar stock and welded material after aging at 1550° F although some reduction in impact properties was observed in samples at 1200 and 1350° F. The deleterious effects of these low aging temperatures are easily discernible in the data obtained on notched base and weld metals. It is significant that these effects occurred at the temperature range where metallographic examination revealed maximum sigma precipitation.

Table 5

	% Fe (Magne-Gage)									
	—Anneal—		—1200° F—		—1350° F—		—1550° F—		1550 + 1950° F	
Type	Base	Weld	Base	Weld	Base	Weld	Base	Weld	Base	Weld
310	0	0	0	0	0	0	0	0	1.5	1.5
321	0	1.5	0	0	0	0	0	0	0	1.0
347	0	2.0	0	0	0	0	0	0	0	0.5

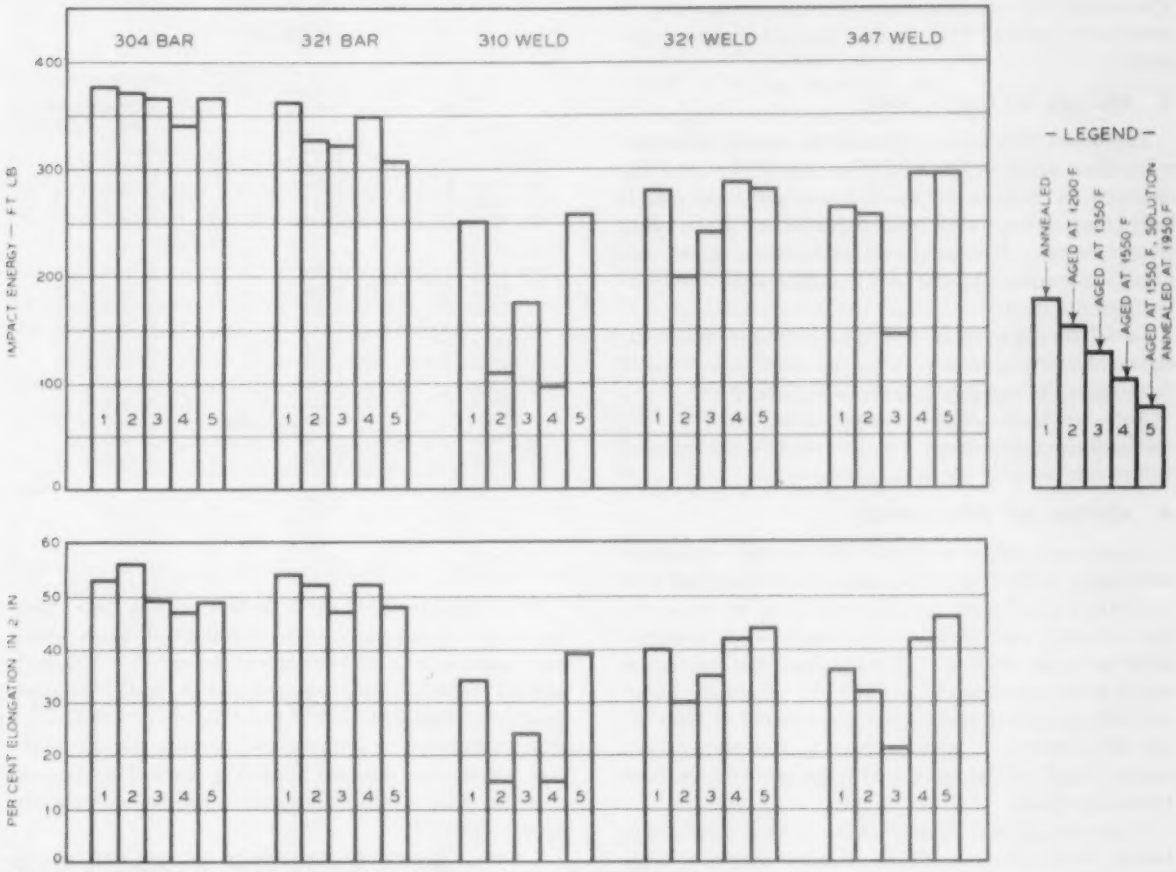


Fig. 5 Tensile-impact results for unnotched bars

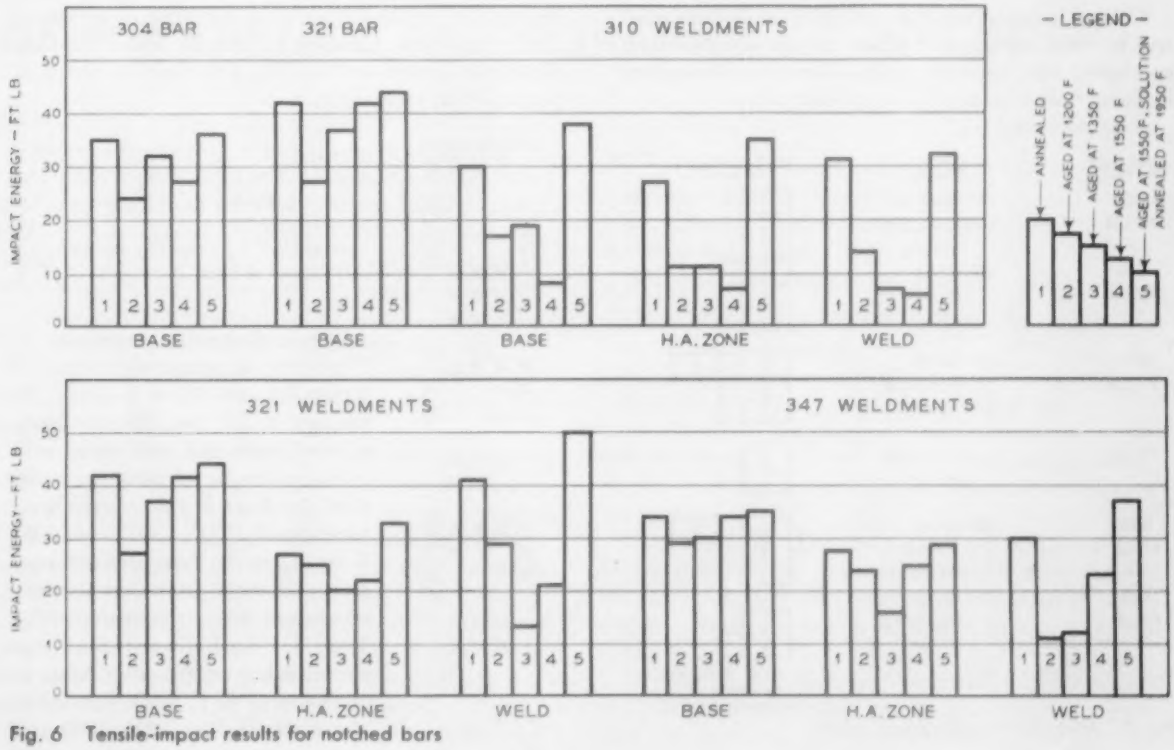


Fig. 6 Tensile-impact results for notched bars

The results indicate that solution treatment at 1950° F effectively restored the original notched impact properties.

3. AISI Type 310 (25Cr – 20Ni)

The unnotched weldments suffered serious embrittlement after aging at 1200, 1350 and 1550° F. A sharp decrease in impact values for notched base metal, heat-affected zone and weld occurred at these aging temperatures. The maximum embrittling effect was noted after aging at 1550° F for both notched and unnotched material.

In all samples where low impact values occurred, sigma phase was present, with the maximum amount forming at the aging temperature of 1550° F.

As a result of solution annealing at 1950° F, the tensile-impact properties were restored to the original values exhibited by the annealed material.

4. AISI Type 347 (18Cr – 8NiCb)

Unnotched welded material was severely embrittled after aging at 1350° F. The notched weld samples were embrittled after aging at 1200 and 1350° F, while the heat-affected zone samples were more notch sensitive after aging at 1350° F. It was noted that maximum sigma phase precipitated at 1350° F. Since the material was not embrittled to any great extent at 1550° F, the effectiveness of the treatment in restoring impact values could not be evaluated from the solution heat treatment given.

In general, it will be noted that in each alloy group tested, weld metal was the most notch sensitive, heat-affected zones less notch sensitive than welds, while base metal exhibited the least notch sensitivity.

The aging temperature at which unnotched material and notched components of the various stainless steel specimens were most adversely affected is summarized in Table 6 with its associated microstructure.

Table 6

Type	*Aging temperature at lowest impact value, ° F*	*Microstructure*
Unnotched		
304 Bar	1550	A + C
321 Bar	1350	A + S + C
310 Welded	1550	A + S + C
321 Welded	1200	A + S + C
347 Welded	1350	A + S + C
Notched		
310 Base	1550	A + S + C
H. A.	1550	A + S + C
Weld	1550	A + S + C
321 Base	1200	A + S + C
H. A.	1350	A + S + C
Weld	1350	A + S + C
347 Base	1200	A + S + C
H. A.	1350	A + S + C
Weld	1200 and 1350	A + S + C
304 Base	1200	A + C
321 Base	1200	A + S + C

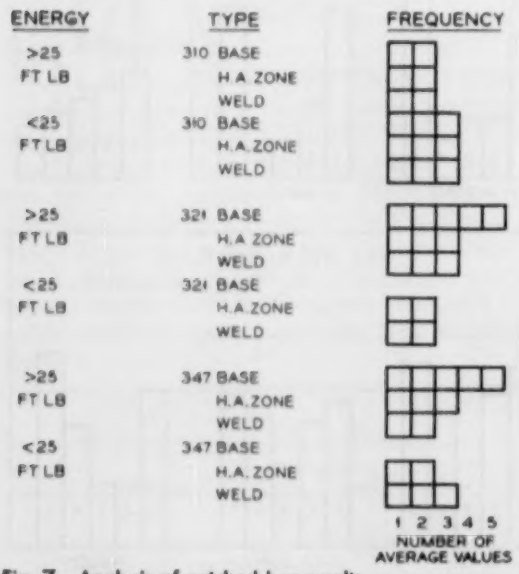
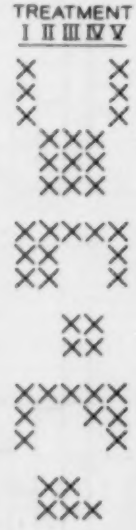


Fig. 7 Analysis of notched bar results

With the exception of Type 304, it was noted that maximum sigma phase was present in all cases where the most serious embrittlement occurred. Although impact properties were restored by the 1950° F solution treatment, sigma phase was not completely dissolved at this temperature. A sigma and carbide free structure was noted after solution annealing Type 310 material at 2100° F for one-half hour, which had been previously aged at 1550° F.

Figure 7 depicts an analysis of notched bar results. The frequency of notched values occurring above and below 25 ft-lb (which represents 50% of the highest notched bar value obtained) is arranged in groups of AISI type and location of notch. The following designations were used in Fig. 7 to indicate the heat treatment for each sample:



Annealed	I
Aged at 1200° F	II
Aged at 1350° F	III
Aged at 1550° F	IV
Aged at 1550° F followed by solution treatment at 1950° F	V

The greater notch sensitivity of Type 310, as compared to that of Types 321 and 347, is evident. In the case of 321 and 347, the heat-affected zones and weld metal were more adversely affected by aging than the base metal. Aging temperatures of 1200°, 1350° and 1550° F for Type 321 heat-affected zone and weld metal decreased the tensile-impact value by more than 50%. Type 347 heat-affected zone was embrittled over 50% after aging at 1200 and 1350° F, while weld metal was embrittled at 1200, 1350 and

1550° F. The tensile-impact toughness for all alloys was over the 50% level in the annealed and the solution annealed conditions.

Conclusions

1. AISI Type 310 material was adversely affected by sigma precipitation at aging temperatures of 1200, 1350 and 1550° F with the most serious embrittlement occurring at 1550° F.

2. Embrittlement of AISI Types 321 and 347 materials due to sigma phase occurred over the narrower aging temperature range of 1200 and 1350° F.

3. Maximum sigma phase precipitation was evident in the most seriously embrittled samples of each alloy group.

4. From the above observations, it may be concluded that stress relief heat treatment following fabrication for AISI Types 321 and 347 may be accomplished at temperatures of from 1500 to 1600° F without danger of sigma embrittlement. However, a higher stress relieving temperature of 1750° F must be employed for Type 310 material to avoid embrittlement.

5. Generally, the notch sensitivity of welds in any of the materials tested was greater than either base metal or heat-affected zones when exposed to sigma-forming temperatures. It is therefore important to eliminate any condition, such as undercutting during welding, whereby a notch might be formed in a weld.

6. The solution heat treatment at 1950° F for one-half hour followed by water quenching was successful in restoring embrittled material of Types 310, 321 and 347 to the original annealed tensile-impact values, although sigma phase was not completely dissolved in every case.

RESEARCH NEWS

INTERNATIONAL COLLECTION OF REFERENCE RADIOGRAPHS OF WELDS

As everybody knows, a great number of radiographs are taken of important welded structures such as boilers, bridges and steel structures. To make possible the correct interpretation of such radiographs and the assessment of the quality of the welds, collections of reference radiographs have been used. These radiographs show welds with typical defects, and the cards to which the reference radiographs are attached contain information with regard to weld defects and radiographic data.

The standard collections which have been made available so far have been accepted only within the country of origin.

One of the first tasks of the International Institute of Welding (IIW) was to prepare a Collection of Reference Radiographs of Welds which could be accepted in all countries represented in the IIW. In Commission 5 a great number of suitable radiographs were examined by experts from the member countries of the IIW and 63 of them were selected and accepted as reference radiographs for various typical weld defects. The complete issue will consist of 79 samples. This collection has thus been accepted at an international level.

The IIW made responsible for executing its decision the following national institutes for technical X-ray service:

Svejsecentralen, Denmark.
Röntgen Technische Dienst, Holland.
Røntgenkontrollen, Norway.
Tekniska Röntgencentralen, Sweden.

The collection employs the card system which has the following advantages:

1. It is easy to enlarge the collection and separate radiograph cards can be replaced by better ones.

2. The cards are punched in accordance with a system which makes it very easy to pick out all radiographs showing a certain weld defect, for instance porosity.

The card system has also made it possible to employ normal transparent film copies, which give exactly the same definition and contrast as the original radiographs. The collection is available in two different forms, viz.:

1. Paper copies pasted on the cards. These copies mounted in a ringbinder, are cheaper and less fragile than the film copies, and can be viewed in normal day-

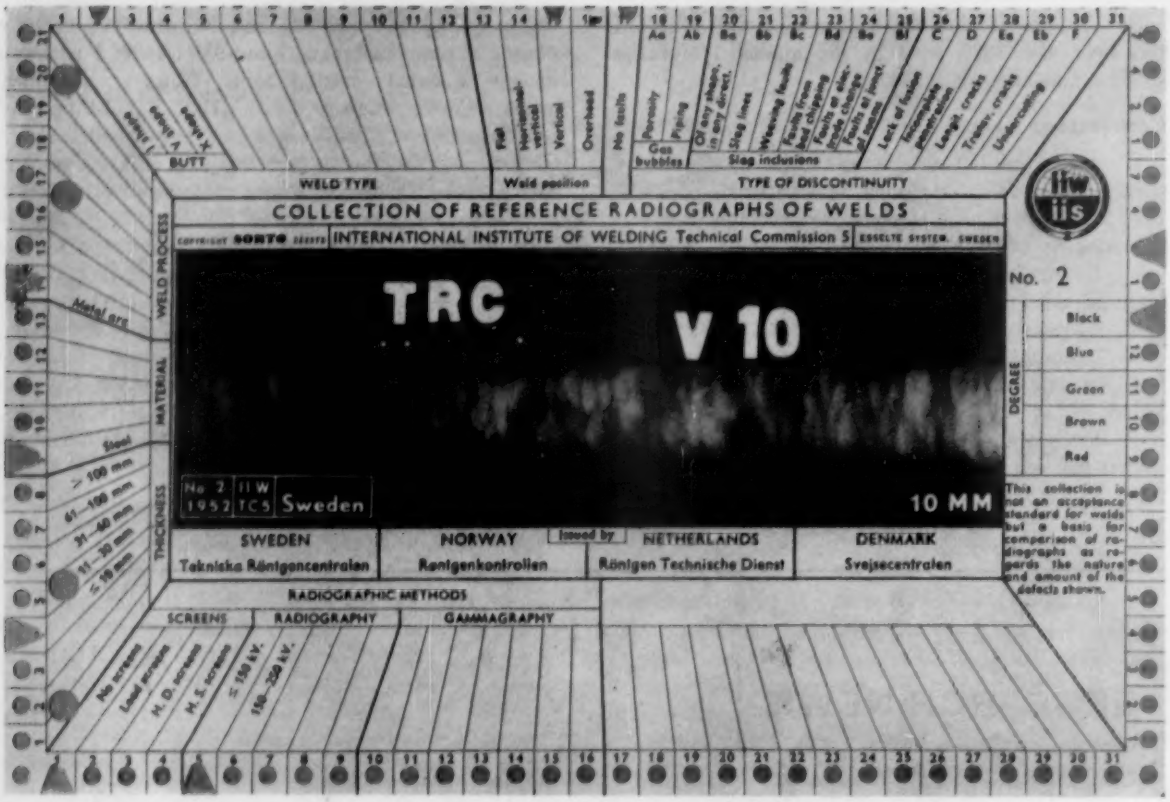


Fig. 1 Reference radiograph (paper copy) showing a sound vertical weld (degree: "black")

light. The paper copies therefore are very suitable for use on the site or for educational purposes.

2. Transparent film copies inserted in a rectangular hole in the card. This type of card is intended for all normal interpretation under office conditions, a special viewing box being necessary.

The cards contain information with regard to marks, weld defects, welding position and plate thickness as well as radiographic data. The text on one side of the card is in English; on the other, French.

Both members of the A.W.S., who are entitled to obtain the collection at about 10% discount, and nonmembers should place their orders with the Central Office: Tekniska Röntgencentralen, Experimentalfältet, Sweden. Karlavägen 20, Stockholm Ö. Bank Sevenska Handelsbanken.

The prices in Sw. Cr. to nonmembers are:

Collection	*Transparent films*	*Paper copies*
Issue 1952 with 1st Supplement 1953	250	180
Complete issue, of which the 2nd Supplement 1954 will be delivered after acceptance by the IIW	320	220

These prices are exclusive of an expedition fee of Sw. Cr. 5:— per copy, and the postage from Central Office to the buyer.

The corresponding amount in any currency valid in Sweden will be accepted.

Fig. 2 Illustration of both collections. Film copies in box (above). Paper copies in ringbinder (below)

(Research News continued on page 96-s)

FATIGUE STRENGTH OF BUTT WELDS IN STRUCTURAL STEELS

Preliminary investigations to improve the fatigue properties of welded joints through removal of reinforcement and use of low-hydrogen electrodes

BY L. A. HARRIS, G. E. NORDMARK AND N. M. NEWMARK

SUMMARY. Fatigue tests have been conducted of full-scale butt welds in carbon steel plates with the stress applied either parallel to or perpendicular to the direction of welding. The welds were deposited with either the E7016 low-hydrogen electrode or the E6010 high-cellulose electrode. The specimens were tested with either the reinforcement on or removed by grinding.

For the specimens tested with the stress perpendicular to the direction of welding, there was no significant difference in the fatigue strength of welds produced with the two types of electrode and tested with the reinforcement on or off. For the specimens tested with the stress parallel to the direction of welding, the scatter is large, but the E7016 welds with the reinforcement either on or off are generally more resistant to repeated loadings than the E6010 welds, especially if failure occurs after a relatively low number of highly stressed cycles.

An extensive re-evaluation of the past fatigue tests of butt welds conducted at the University of Illinois has been made to evaluate the use of different welding procedures.

Introduction

Object and Scope of Investigation

It has been the purpose of most of the previous fatigue tests of welded joints to provide sufficient experimental data from which it would be possible to determine, quantitatively, the fatigue strength of welded joints of different types, and thence to determine allowable stresses for use in the design of structures subjected to repeated loads. With advances in welding techniques, recent interest has been directed toward methods of improving the fatigue behavior of weldments. During the last three years, the Ohio River Division Laboratories of the Corps of Engineers, U. S. Army has sponsored a research program at the University of Illinois which has had as its chief objective a comparison of the properties of welds produced with the E7016 low-hydrogen electrode and the E6010 high-cellulose electrode.

The first phase of the study of the fatigue behavior of welded joints prepared with E7016 and E6010 electrodes was an investigation of the fatigue properties of small scale, polished, all-weld-metal specimens.[1] The results of the tests of the all-weld-metal specimens indicated that the weld metal deposited with the E7016 electrode had a fatigue strength which was at least 17,000 psi greater than that of the weld metal deposited with the E6010 electrode. On the basis of the encouraging results from the fatigue tests of the low-hydrogen weld metal, a series of fatigue tests was undertaken to determine whether this improvement would be reflected in fatigue tests of full-scale welded joints. The present investigation represents the first phase of this study of full-scale welded joints, a study of the fatigue properties of butt welds.

It is the purpose of the current series of tests to compare the fatigue and static properties of butt welds produced with E6010 or E7016 electrodes. Two types of butt weld specimens were tested: the longitudinal butt weld with the applied stress parallel to the direction of welding and the transverse butt weld with the applied stress perpendicular to the direction of welding. The butt welds were tested either with the reinforcement on or with the reinforcement removed by grinding and were subjected to a zero-to-tension stress cycle.

In order to describe more completely the fatigue behavior of butt welds, an extensive review of the fatigue tests of longitudinal and transverse butt welds conducted previously at the University of Illinois has been included in this paper. The past specimens were welded with different joint preparations, in different positions, and with different electrodes. The tests reported are those which employed either a zero-tension or a tension-compression stress cycle and the joints were tested either with the mill scale on or with the mill scale off. Some specimens were subjected to special pre- or postweld treatments.

Description of Steel

The steel plate used in the present tests was ordered to comply with the American Bureau of Shipping specification for Type B steel. The average chemical analysis and physical properties are included in Table 1. The steel, which was supplied as $^3/_4$-in. rolled plates, meets both the ABS specification and the ASTM A7 specification for chemical composition, but the average physical

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Presented at the Thirty-Fifth National Fall Meeting, AWS, held in Chicago, Ill., Nov. 1-5, 1954.

Table 1—Properties of Plate Material Used in Past and Present Transverse Butt-Weld Fatigue Tests

Steel	Physical Properties: Yield point, psi	Tensile strength, psi	% elongation in 8 in.	Reduction of area, %	Chemical content, %: C	Mn	P	S	Si	Fatigue strength*: $f_{100,000}$, psi	$f_{2,000,000}$, psi	k
Bulletin 310,† ASTM A7	31,000	54,500	34	61	0.15	0.50	0.024	0.022	0.06	...	30,300+‡	0.10
Bulletin 327, ASTM A7	34,800	61,300	31	54	0.26	0.47	0.015	0.034	0.01	49,800‡	31,600+‡	0.18
										59,600§	...	0.18
Bulletin 344, ASTM A7												
Series X	30,700	59,000	30	54	0.25	0.49	0.009	0.029	0.00	...	...	..
Series Y	29,500	62,300	29	52	0.24	0.47	0.017	0.029	0.03	...	...	..
Series Z	31,000	60,200	30	59	0.19	0.51	0.018	0.029	0.01	...	...	..
All but above	33,600	63,300	30	54	0.26	0.54	0.010	0.034	0.01	...	...	..
Bulletin 350, ASTM A7	38,200	62,700	30	57	0.20	0.42	0.015	0.027	0.23	...	...	..
Bulletin 384, ASTM A7	36,100	58,900	31	53	0.21	0.48	0.013	0.037	..	49,100‡	34,700‡	0.10
1953-54, ASTM A7	33,300	57,400	33	62	0.17	0.68	0.016	0.039	0.03	...	34,600‡	0.18
											35,300+§	0.18

* Zero-tension stress cycle.
† Tests reported in Bulletin 302.
‡ Reinforcement on.
§ Reinforcement off.
‖ Ordered to American Bureau of Shipping Specification for Type B steel.

properties do not meet either specification for tensile strength, the average tensile strength being only 57,400 psi.

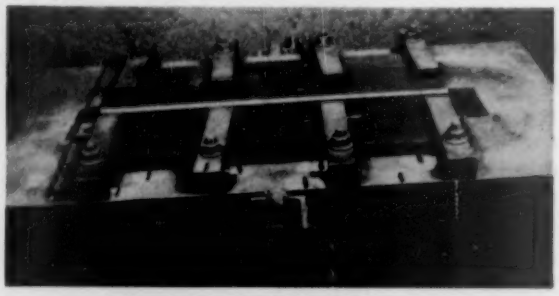
Preparation of Longitudinal Butt Welds

The details of the completed butt weld specimens are shown in Fig. 1. The center section, containing the test weld, was made up of two 6-in. wide pieces, machined to provide for a double-V butt weld having a 60-deg included angle and a 1/16-in. root opening. After the longitudinal weld had been completed, the center section was welded to two pull heads for installation in the testing machine.

In making the longitudinal weld, the two halves of the center section were first securely bolted to the welding jig, shown in Fig. 2, which could be rotated about a horizontal axis to permit deposition of all passes in the flat position. After deposition of the first pass, the weld was back chipped until no visible defects were present. Fifteen minutes of air cooling was allowed between the first and second passes but only 5 min between all succeeding passes. The specimens were air cooled after deposition of the last pass. The welding sequence

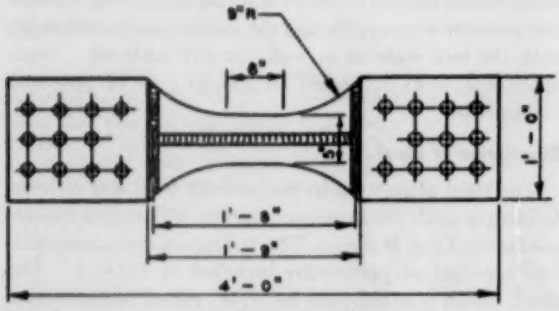
Table 2—Weld Procedures

Electrode	Diameter, in.	Current, amp	Voltage, v	Open-circuit voltage, v
Transverse butt welds				
E6010				
First pass	5/16	125	25	81
2–6 pass	5/16	160–170	26	83
E7016				
First pass	5/16	145	20	82
2–6 pass	5/16	200	20	83
Longitudinal butt welds				
E6010				
First pass	5/16	135	24	85
2–6 pass	5/16	150–160	25	85
E7016				
First pass	5/16	165	20	84
2–6 pass	5/16	200	21	86

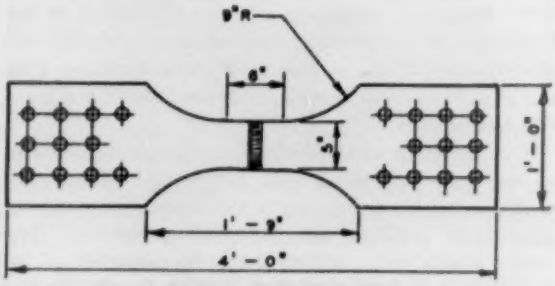


Jig in position for second pass

Fig. 2 Welding jig for longitudinal butt-weld specimens



(a) Longitudinal butt weld



(b) Transverse butt weld

Fig. 1 Details of butt-weld specimens

Table 3—Results of Present Longitudinal Butt-Weld Fatigue Tests

	E6010 welds					E7016 welds			
		Cycles to	Fatigue strength*				Cycles to	Fatigue strength*	
Spec.	Stress, psi	failure, 10^3	$f_{100,000}$, psi	$f_{2,000,000}$, psi	Spec.	Stress, psi	failure, 10^3	$f_{100,000}$, psi	$f_{2,000,000}$, psi
			Specimens tested with the weld reinforcement on						
H7	40,100	86.0	39,300	...	H9	40,000	184.0	43,400	...
H19	30,000	451.7	36,400	24,700	H74	29,500	751.1	...	26,000
H77	30,000	417.4	36,200	24,400	H88	30,000	447.3	36,700	24,800
H79	36,000	89.2	35,600	...	H90	39,500	177.3	42,600	...
H91	29,600	304.5	34,200	...	H98	30,000	1223.7	...	28,200
H97	40,000	123.0	41,100	...	H100	40,000	207.7	44,000	...
H103	36,000	180.6	38,900	...					
		Avg	37,400	24,500			Avg	41,700	26,300
			Specimens tested with the weld reinforcement off						
H11	40,000	124.2	41,100	...	H18	40,000	503.7	49,400	...
H20	40,000	38.5	36,300	...	H76	30,000	4514.7†	...	30,000+
H75	30,000	2883.2	...	30,000	H78	29,500	1244.0	...	27,800
H89	39,800	169.6	42,600	...	H92	39,900	361.5	47,100	...
H93	29,500	1845.8	...	29,200	H96	40,400	400.1	48,400	32,800
H99	40,000	82.9	39,000	...	H102	30,000	3189.1†	...	30,000+
H101	30,000	1803.7	...	29,600					
		Avg	39,800	29,600			Avg	48,300	30,200+

* $k = 0.13$.
† Specimen did not fail.

was such that a change of electrode occurred in the test section in each pass of the weld, adjacent passes were welded in opposite directions, and changes of electrode in adjacent passes did not occur one over the other. The $^3/_{16}$-in. diam E6010 and E7016 electrodes were operated at the current and voltage levels, given in Table 2, which were measured on portable meters connected as close to the arc as possible. After the completion of welding, the specimens were machined to the shape shown in Fig. 1 and the edges were draw-filed.

A portable disk grinder was employed to remove the weld reinforcement and the mill scale from the entire center section for those specimens to be tested with the reinforcement off. The grinding was started with a 36 grit wheel and finished with a 120 grit wheel in such a manner that the scratches were parallel to the direction of loading. The mill scale and the rolling defects were ground off in the section between pullheads to prevent failure at irregularities out of the test section.

Preparation of Transverse Butt Welds

The transverse butt weld specimen, shown in Fig. 1, had an increased width at the joint during welding to enable the ends of the weld to be machined from the specimen before testing. The plate was saw cut at the joint and was prepared in a shaper for a double-V butt weld having an included angle of 60 deg and a $^1/_{16}$-in. root opening. The welding procedure employed 6 passes and the $^3/_{16}$-in. diam E6010 and E7016 electrodes were operated at current and voltage levels given in Table 2.

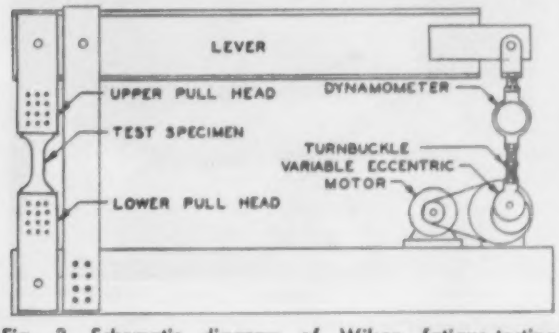


Fig. 3 Schematic diagram of Wilson fatigue-testing machine

Table 4—Results of Present Plain Plate Fatigue Tests

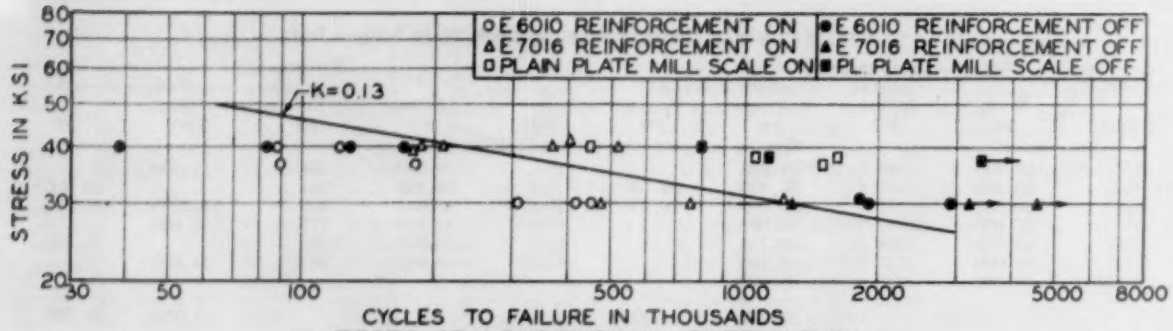
Spec.	Stress, psi	Cycles to failure, 10^3	Fatigue strength* $f_{100,000}$, psi	$f_{2,000,000}$, psi
		Mill scale on		
H10	35,500	1508.0	...	35,200
H46	40,000	450.3	...	33,000
H49	37,000	1078.3	...	34,100
H58	37,200	1627.2	...	36,200
			Avg.	34,600
		Mill scale off		
H51	39,000	810.9	...	34,700
H56	37,400	1137.5	...	34,800
H61	36,400	3454.1[b]	...	36,400+
			Avg	35,300+

* $k = 0.18$.
[b] Specimen did not fail.

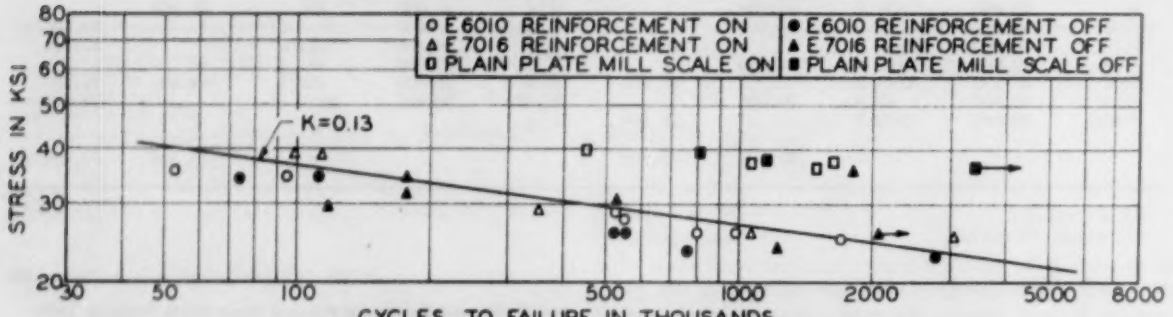
The other details of preparation were the same as for the longitudinal butt welds, except that the specimen was allowed to cool for 5 min between all passes. Those specimens to be tested with the reinforcement removed were ground in the same manner as the longitudinal butt-weld specimens, but only for a distance of about 2 in. from each edge of the weld.

Test Procedures

The fatigue tests were performed at room temperature in two 200,000-lb capacity, Wilson lever type fatigue testing machines which ran at a speed of approximately 200 cpm. The essential features of the machine, shown in Fig. 3, are a variable throw eccentric which transmits

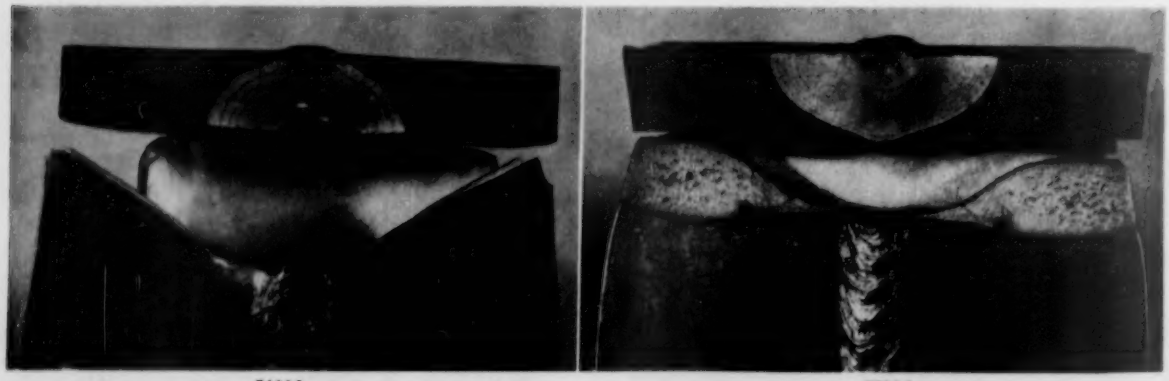


a. TESTS OF LONGITUDINAL BUTT WELDS



b. TESTS OF TRANSVERSE BUTT WELDS

Fig. 4 Results of present fatigue tests of butt welds



E6010 E7016

(a) Specimens tested with the weld reinforcement on

E6010 E7016

(b) Specimens tested with the weld reinforcement removed by grinding

Fig. 5 Typical fatigue fractures of longitudinal butt welds

force through a dynamometer (for determining the load on the specimen) to a lever which in turn transmits the force to the upper pull head at a multiplication ratio of approximately 15 to 1. The variable throw eccentric is adjusted to give the desired range of stress before the test is started and the maximum load is controlled by the adjustable turnbuckle mounted between the eccentric and the dynamometer. The stress is determined by an Ames dial which measures the vertical deflection across the throat of the dynamometer to the nearest 0.001 in. All of the present tests were run on a stress cycle (referred to as a zero-tension cycle) which varied from a low tension, required to keep the bearings seated properly, to a maximum tension.

After a specimen had been bolted in the fatigue machine, a stress equal to the maximum desired stress was first statically applied to the specimen. Plastic straining occurred for those specimens to be tested above their yield points; hence, it was necessary to allow sufficient time for the specimens to strain statically under the maximum load before the load could be maintained under repeated loadings.

The fatigue machines were run continuously. They were equipped with a micro-switch which stopped the machine if the maximum deflection of the specimen increased suddenly. The load was checked frequently at the start of a test, but later only as often as necessary to maintain the desired load. Failure is defined in these tests as the number of cycles of loading resisted by the specimen before the fatigue crack was large enough to actuate the micro-switch which stopped the fatigue machine.

Tests of Longitudinal Butt Welds in ASTM A7 Steels

Present Fatigue Tests of Longitudinal Butt Welds

The results of the tests of the longitudinal butt welds and of the corresponding plain plates are presented in Table 3 and 4, respectively, and in Fig. 4. The fatigue strengths corresponding to failure at 100,000 and at 2,000,000 cycles (f100,000 and f2,000,000) have been computed from the empirical relationship $f = S(N/n)^k$, in which S is the stress corresponding to a test failure after N cycles, f is the stress corresponding to failure after the desired number of cycles, n, and k is an experimentally determined constant.[3] For those specimens having a fatigue life greater than 2,000,000 cycles, the value of S has been used as the fatigue strength at 2,000,000 cycles.

Based on the results of previous tests, the values of k have been set equal to 0.13 for the weld tests and to 0.18 for the plain plate tests. A variation in the value of k from 0.13 to 0.18 changes the value of the computed fatigue strength by a maximum of approximately 9% (for failure occurring at 500,000 cycles). The closer the experimental number of cycles to the desired number of cycles, the smaller will be the difference in the fatigue strengths computed from the different values of k.

The plain plate average fatigue strengths corresponding to failure at 2,000,000 cycles, 34,600 psi for the specimens with the mill scale on and 35,300 psi for the specimens with the mill scale off, were greater than the yield strength of the plate, which was 33,300 psi.

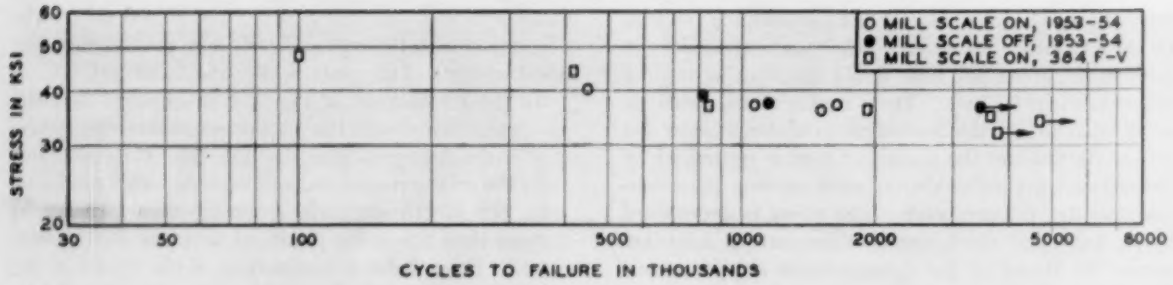
In the SN diagram of Fig. 4, it is apparent that the specimens tested with the reinforcement removed generally had a higher fatigue strength than the specimens with the reinforcement on, and that the welds produced with the E7016 electrode generally were stronger in fatigue than the welds produced with the E6010 electrode. From Table 3, comparison of the results of the specimens with the different electrodes, tested with the weld reinforcement on, shows that the welds produced with the E7016 electrode have an average fatigue strength for failure at 100,000 cycles about 4000 psi greater than those produced with the E6010 electrode. For failure at 2,000,000 cycles, the E7016 welds are about 2000 psi stronger than the E6010 welds.

Removal of the weld reinforcement increased the fatigue strength, but not uniformly. The E7016 longitudinal butt welds had fatigue strengths which were increased a greater amount for failure at 100,000 cycles than for failure at 2,000,000 cycles. On the other hand, the increase in the fatigue strength of the E6010 welds for failure at 2,000,000 cycles was considerably greater than the increase in the fatigue strength for failure at 100,000 cycles. Therefore, for failure occurring at 100,000 cycles, the E7016 longitudinal butt welds tested with the reinforcement off are about 9000 psi stronger than the E6010 welds, whereas for failure at 2,000,000 cycles the two types of weld have about the same fatigue strength.

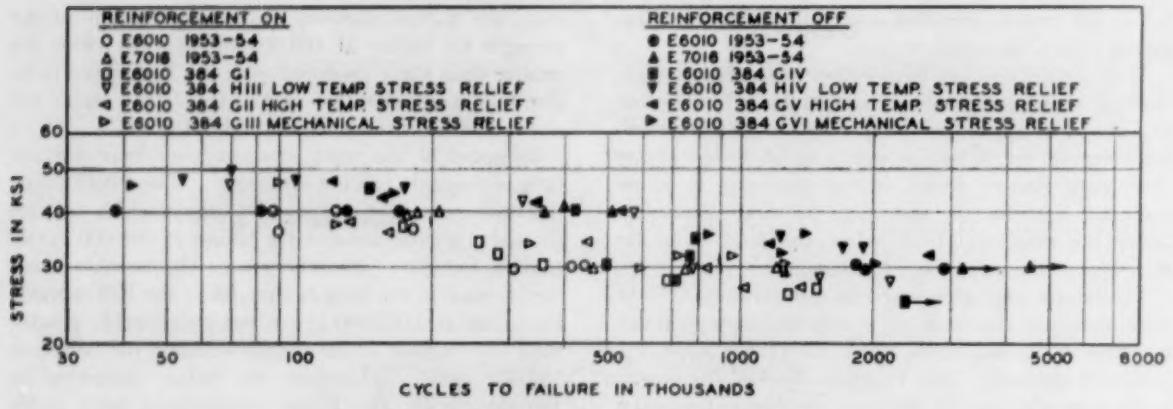
In general, the results of the fatigue tests of the longitudinal butt welds, both with the weld reinforcement on and with the weld reinforcement removed by grinding, indicate that the E7016 welds are likely to be more resistant to repeated loadings, especially under conditions in which failure occurs after a relatively low number of high stress cycles.

With the exception of one E6010 weld, all of the specimens tested with the weld reinforcement on started to fail at the surface of the weld. Although all of the E6010 welds with the reinforcement on contained defects (porosity or inclusions) in the weld metal, only the one fracture originated at a defect in the weld metal. The fracture surfaces of the E7016 specimens did not contain defects in the weld metal. About half of the fractures originated at the surface of the weld where the electrode had been changed; however, these failures occurred at about the same fatigue strength as the failures which originated at the surface of the weld away from the change in electrode. Typical fracture surfaces of the longitudinal butt welds are shown in Fig. 5.

All of the failures of the E6010 welds tested with the weld reinforcement ground off seemed to be initiated at defects in the weld metal. Only one of the failures of the E7016 welds tested with the reinforcement off initiated from a defect (near the surface) in the weld metal, the remainder of the failures initiated from the surface of the weld.

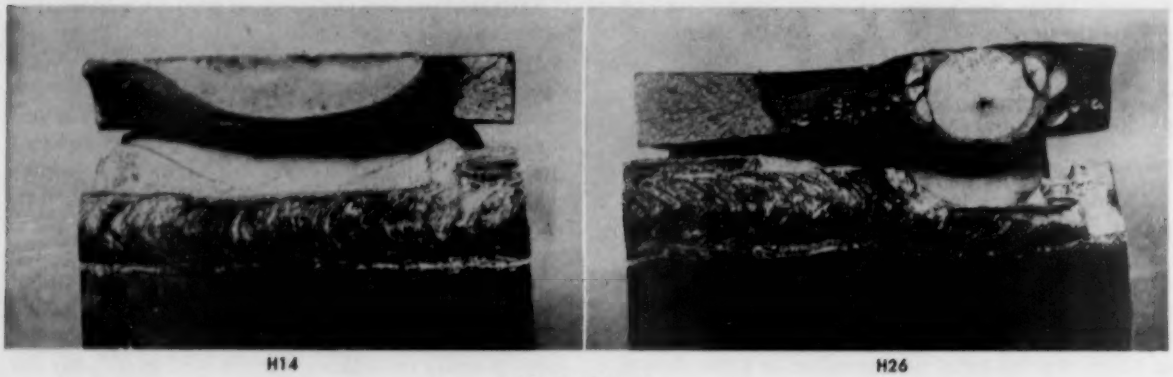


a. PLAIN PLATE TESTS

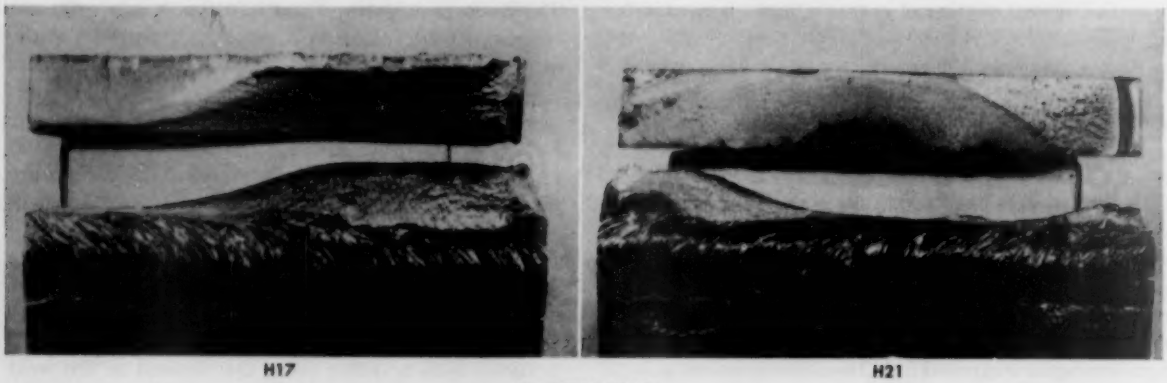


b. LONGITUDINAL BUTT WELD TESTS

Fig. 6 Results of past and present fatigue tests of longitudinal butt welds



(a) E6010 Welds



(b) E7016 Welds

Fig. 7 Typical fatigue fractures of transverse butt welds with the reinforcement on

Table 5—Summary of Results of Past and Present Fatigue Tests of Longitudinal Butt Welds

Bulletin	Electrode	Position of welding	Special pre- or postweld treatments	Average fatigue strength* $f_{100,000}$, psi	Average fatigue strength* $f_{2,000,000}$, psi	k
			Specimens tested with the weld reinforcement on			
384	E6010	Flat	None	38,500	24,300	0.15
1953–54†	E6010	Flat	None	37,400	24,500	0.13
1953–54	E7016	Flat	None	41,700	26,300	0.13
384	E6010	Flat	High-temperature stress relief	40,300	26,100	0.14
384	E6010	Flat	Mechanical stress relief	39,900	27,700	0.13
384	E6010	Flat	Low-temperature stress relief	49,900	28,200	0.19
			Specimens tested with the weld reinforcement off			
384	E6010	Flat	None	49,300	25,300	0.23
1953–54†	E6010	Flat	None	39,800	29,600	0.13
1953–54†	E7016	Flat	None	48,300	30,200+	0.13
384	E6010	Flat	High-temperature stress relief	48,300	32,600	0.13
384	E6010	Flat	Mechanical stress relief	44,500	31,500	0.12
384	E6010	Flat	Low-temperature stress relief	46,300	32,700	0.11

* All specimens tested on a 0-tension stress cycle.
† Present series of tests.

Review of Previous Longitudinal Butt-Weld Fatigue Tests

The results of the past[3] and the present longitudinal butt-weld fatigue tests are presented in Table 5 and in Fig. 6. The properties of the plain plate used in these tests are given in Table 1.

(*a*) *Specimens Tested with the Weld Reinforcement On:* For the longitudinal butt welds tested in the as-welded condition, the E6010 welds of the present (1953–54) series of tests have about the same average fatigue strengths as the previous tests, but the E7016 welds of the present series have an average fatigue strength which is about 10% greater than the fatigue strength of the previous E6010 welds. The previous tests of specimens with high temperature or mechanical stress relief treatments have average fatigue strengths which are about as great as that of the E7016 welds. Only the E6010 welds subjected to a low-temperature, stress-relief treatment had a substantially greater (about 10 to 20%) fatigue strength than the as-welded E7016 specimens.

(*b*) *Specimens Tested with the Weld Reinforcement Off:* Without subsequent treatment, the previously tested E6010 welds had a higher fatigue strength for fracture at 100,000 cycles and a lower fatigue strength for fracture at 2,000,000 cycles than the 1953–54 series of E6010 welds. The past specimens without a stress relief treatment had average fatigue strengths as great as, or greater than, the stress relieved specimens for failure at 100,000 cycles, but all three stress relief treatments (high-temperature, mechanical and low-temperature) significantly increased the fatigue strength corresponding to failure at 2,000,000 cycles. The E7016 welds performed about as well as any of the longitudinal welds with the reinforcement off.

Removal of the weld reinforcement generally increased the fatigue strength by 10 to 20% except for

Table 6—Results of Present Transverse Butt Weld Fatigue Tests

E6010 Welds					E7016 welds				
Spec.	Stress, psi	Cycles to failure, 10^3	Fatigue strength* $f_{100,000}$, psi	Fatigue strength* $f_{2,000,000}$, psi	Spec.	Stress, psi	Cycles to failure, 10^3	Fatigue strength* $f_{100,000}$, psi	Fatigue strength* $f_{2,000,000}$, psi
			Specimens tested with the weld reinforcement on						
H12	29,400	537.9	36,600	24,800	H13	29,100	354.8	34,300	...
H14	28,000	539.4	34,900	23,600	H17	39,000	117.8	39,800	...
H22	26,000	802.2	...	23,100	H21	26,000	1097.0	...	24,000
H26	35,000	95.3	34,800	...	H25	39,600	98.8	39,600	...
H32	26,300	984.0	...	24,000	H31	24,200	1243.8	...	21,800
H48	36,000	53.2	33,200	...	H65	25,700	3056.2	...	25,700
H54	25,000	1695.4	...	24,500					
		Avg	34,900	24,000			Avg	37,900	23,800
			Specimens tested with the weld reinforcement off						
H28	35,000	112.7	35,600	...	H27	32,000	179.1	34,600	...
H30	26,000	530.1	32,300	21,900	H39	26,000	2079.7†	...	26,000+
H40	23,400	771.0	...	20,700	H43	35,200	177.1	37,900	...
H44	25,400	541.2	31,600	21,400	H45	36,100	1808.9	...	35,600
H50	35,000	74.0	33,600	...	H57	30,500	533.7	38,000	25,700
H60	23,000	2810.9	...	23,000	H64	30,500	118.8	31,200	...
		Avg	33,300	21,800			Avg	35,400	29,100+

* $k = 0.13$.
† Specimen did not fail.

(a) E6010 weld (b) E7016 weld

Fig. 8 Typical fatigue fractures of transverse butt welds with the reinforcement ground off

the welds which had a low-temperature stress-relief treatment, in which case the fatigue strength corresponding to failure at 100,000 cycles was less after removal of the weld reinforcement.

Tests of Transverse Butt Welds in ASTM A7 Steels

Present Fatigue Tests of Transverse Butt Welds

The results of the transverse butt weld tests are plotted in an *SN* diagram in Fig. 4 and are summarized in Table 6. One of the most important features of the *SN* diagram is the relatively narrow scatter band within which the test results fall, regardless of the variations in the welding procedure. For the specimens tested in the as-welded condition, both the E6010 and the E7016 welds have the same average fatigue strength for failure at 2,000,000 cycles, whereas the E7016 welds have an average fatigue strength for failure at 100,000 cycles which is about 10% greater than the average fatigue strength of the E6010 welds. For the specimens tested with the weld reinforcement ground off, the E7016 welds have an average fatigue strength slightly greater than the E6010 welds for failure at 100,000 cycles and about 30% greater for failure at 2,000,000 cycles. The large difference in the average fatigue strengths in the latter case is caused by the exceptionally high fatigue strength of the E7016 specimen tested at 36,000 psi, which resisted 1,800,000 cycles before failing in the plate away from the weld.

Removal of the weld reinforcement has decreased the fatigue strength of the E6010 welds. The E7016 welds with the reinforcement off also have a lower fatigue strength than the E7016 welds with the reinforcement on for failure at 100,000 cycles; however, the fatigue strength for failure at 2,000,000 cycles is greater by about 20%.

For E6010 welds with the reinforcement on, the fracture originated more often in the weld metal (5 specimens) than at the edge of the weld (2 specimens). In order to improve the fatigue properties of the E6010 welds, it appears that both regions of the joint would have to be strengthened. In contrast, all of the E7016 welds tested with the reinforcement on started to fail at the edge of the weld, indicating that the fatigue properties of the complete joint are controlled by the fatigue strength of the region at the edge of the weld. Photographs of typical fracture surfaces are shown in Fig. 7.

All but one of the fatigue fractures of the transverse butt welds with the reinforcement ground off originated in the weld metal at an internal inclusion or gas pocket. The one exception, an E7016 specimen, failed in the base plate away from the weld at a higher fatigue strength than the other specimens. It is possible that the slight reduction in the average fatigue strengths of the specimens with the weld reinforcement ground off was caused by the defects in the weld metal. Photographs of typical fatigue fractures are shown in Fig. 8.

Scope of Study of Previous Fatigue Tests of Transverse Butt Welds in ASTM A7 Steels

In order to determine if any advantage might be obtained from the use of the various welding techniques, a re-evaluation has been made of the fatigue tests of transverse butt welds conducted previously at the University of Illinios.[3–7] The design of the specimens tested previously was generally of the types shown in Fig. 1 although some of the specimens were of different thicknesses and others were of a reduced size. The results of the past tests were analyzed to study the influence of the following variables: (1) the type of electrode, (2) the welding procedure, (3) the location of fracture, (4) the type of stress cycle and (5) the removal of the weld reinforcement.

The physical properties and the chemical analyses of the A7 steels used in the past and the present tests are summarized in Table 1. Although several of the steels do not meet the ASTM A7 specification for yield point and tensile strength, the tensile properties and the chemical compositions of the different steels are similar. Comparison of the average fatigue strengths of the plate materials indicates that, in the absence of stress raisers, the steels behave in somewhat the same manner to repeated stresses. Only the steel used in the present (1953–54) program had a fatigue strength corresponding to failure at 2,000,000 cycles which exceeded the coupon yield strength.

Review of Past and Present Fatigue Tests of Transverse Butt Welds with the Reinforcement On

Comparison of the welds produced with the different

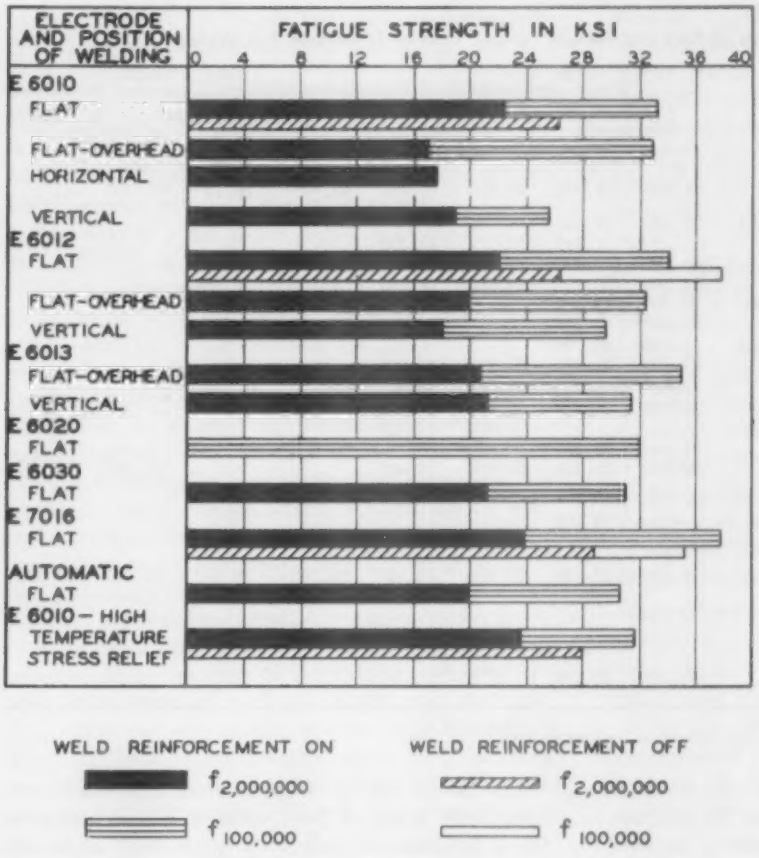


Fig. 9 Average fatigue strengths of past and present transverse butt welds: Zero-tension cycle

electrodes is facilitated by use of the summary Table 7, which contains the average fatigue strengths of the reported tests. Figure 9 is a bar graph of the average fatigue strengths of the tests on a zero-tension cycle and Fig. 10 shows a summary *SN* diagram which contains all of the test results of welds in the as-welded condition. The latter diagram shows the very large amount of scatter encountered in the tests of the butt welds prepared with the various types of electrode. For instance, for a stress cycle of 0 to 20,000 psi, a transverse butt weld might fail after as few as 200,000 cycles of loading or might withstand as many as 8,000,000 cycles without failing.

In evaluating the test results in terms of an average fatigue strength corresponding to failure at a given number of cycles, the large amount of scatter is likely to be overlooked. The average results which are dis-

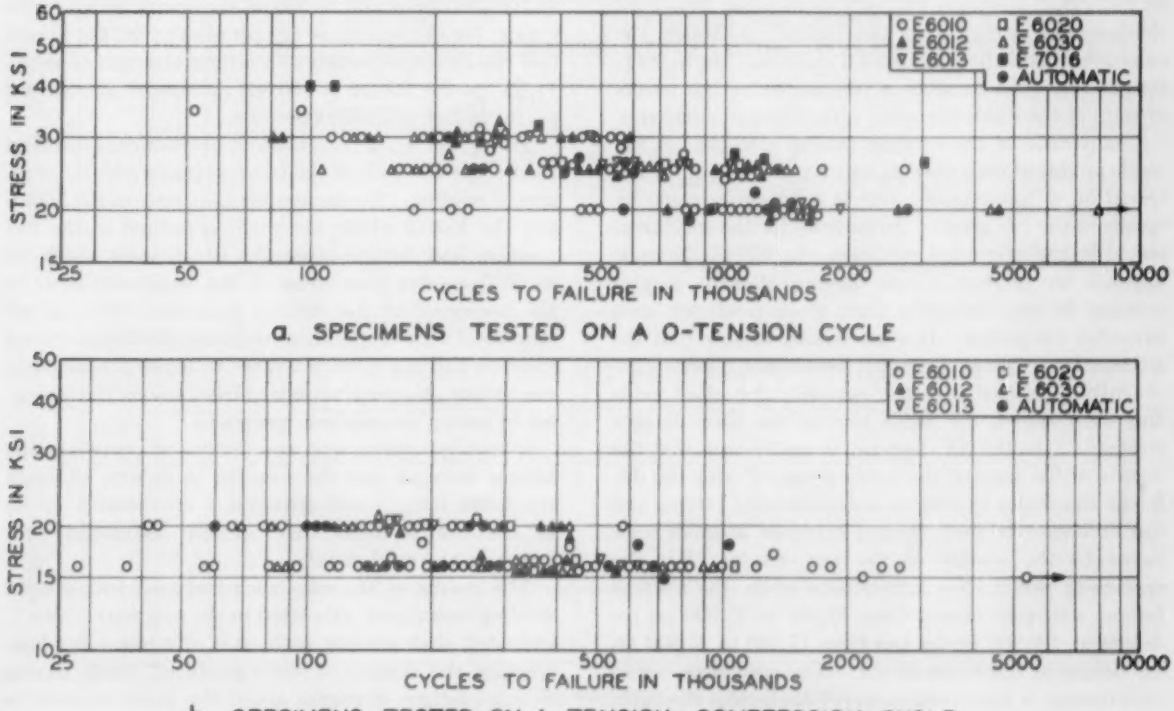


Fig. 10 Summary of results of all past and present fatigue tests of transverse butt welds in the as-welded condition

Table 7—Average Results of Past and Present Fatigue Tests of Transverse Butt Welds

Electrode	Position of welding	Fatigue strength: Weld reinforcement on — Zero-tension $f_{100,000}$, psi	Fatigue strength: Weld reinforcement on — Zero-tension $f_{2,000,000}$, psi	Fatigue strength: Weld reinforcement on — Tension = compression $f_{100,000}$, psi	Fatigue strength: Weld reinforcement on — Tension = compression $f_{2,000,000}$, psi	Fatigue strength: Weld reinforcement off — Zero-tension $f_{100,000}$, psi	Fatigue strength: Weld reinforcement off — Zero-tension $f_{2,000,000}$, psi	Fatigue strength: Weld reinforcement off — Tension = compression $f_{100,000}$, psi	Fatigue strength: Weld reinforcement off — Tension = compression $f_{2,000,000}$, psi
E6010	Flat	33,200	22,300	20,500	13,500	33,300–54,200*	26,400	28,000	...
	Flat-overhead	32,900	17,000	...	...	...	...	...	...
	Horizontal	...	17,800	...	12,200	...	...	...	...
	Vertical	25,800	19,000	16,900	11,800	...	...	...	...
E6012	Flat	34,200	22,100	22,600	12,700	38,100	26,500	...	...
	Flat-overhead	32,600	20,000	...	...	...	...	...	...
	Vertical	29,800	18,100	...	...	...	...	...	...
E6013	Flat-overhead	35,200	20,700	...	...	...	...	...	...
	Vertical	31,600	21,300	21,500	13,600	...	...	...	...
E6020	Flat	32,000	...	22,000	13,500	...	...	...	...
E6030	Flat	31,200	21,200	21,600	12,800	...	...	...	...
	Flat-overhead	...	...	20,000	13,800	...	...	...	...
E7016	Flat	37,900	23,800	...	...	35,400	29,100	...	...
Automatic	Flat	30,800	20,000	21,000	12,800	...	...	23,000	14,900
	Specimens prepared with pre- and postweld special treatments								
Not given Each pass peened	Flat	...	22,300	...	...	...	...	...	...
E6010 High temperature stress relief	Flat	31,900	23,700	21,300	15,100	39,300–53,300*	28,000	24,500	16,600
E6012 High temperature stress relief	Flat	...	...	...	...	36,800	31,200	...	...
Not given High temperature stress relief	Flat	33,300	23,200	...	...	...	...	...	...

* The range of the results was so large that an average was not computed.

cussed in the paper are averages only, and the deviation from the average, clearly indicated by the *SN* diagram, must be considered in designing a structure to resist repeated loadings. It is likely that the test results from an individual specimen will vary as much as 30% from the averages reported in the tables. Although the comparison must be considered a crude one, the average fatigue strengths do allow a comparison of the results of tests of the welds prepared with different electrodes.

Comparison of the average fatigue strengths of the welds produced with the different types of electrode and tested on a zero-tension cycle is most easily made by means of the bar graph. In general, for the specimens tested in the as-welded condition, the E7016 electrode appears to produce welds having slightly greater average fatigue strengths than those produced with the other electrodes. It is interesting to note that the automatically prepared welds behaved no more consistently in fatigue than the manually deposited welds and were among the welds having the lower fatigue strengths. In the *SN* diagram, it can be seen that the results of the tests of the welds prepared with the different electrodes overlap to a considerable extent, and the difference in their fatigue behavior is small compared to the scatter of the test results. For the specimens tested on a zero-tension cycle, the average fatigue strengths ranged from 25,800 to 37,900 psi for failure at 100,000 cycles and from 17,000 to 23,800 psi for failure at 2,000,000 cycles. The specimens tested on a tension = compression cycle have fatigue strengths which are about 60 to 70% of the zero-tension fatigue strengths.

The lowest fatigue strengths from individual specimens were obtained from tests of E6010 specimens. On a zero-tension cycle, the lowest test result corresponded to a fatigue strength of 21,500 psi for failure at 100,000 cycles and 14,500 psi for failure at 2,000,000 cycles; for the tension = compression cycle, the lowest test results corresponded to a fatigue strength of about 14,000 psi for failure at 100,000 cycles and about 9000 psi for failure at 2,000,000 cycles.

There was a fairly consistent relationship between the fatigue strength of the test specimens and the position of welding. In the results of the tests of the E6010 and the E6012 welds, the welds deposited in the flat position had fatigue strengths which were about 10 to 20% greater than those of the welds deposited in the horizontal or the vertical positions. The limited number of tests of specimens welded in the flat-overhead position had too great a scatter to make a reasonable comparison, the results varying from among the strongest to among the weakest specimens.

Generally, there was no correlation between the fatigue strength and the location of failure, although the lower fatigue strengths (on a zero-tension cycle) of the E6010 welds were usually associated with failure in the weld metal.

The results of the specimens prepared with special welding techniques, tabulated in the summary Table 7, indicated that peening each pass or stress relief heat treating the completed weld produced welds having average fatigue strengths about the same as those of the as-welded specimens. Therefore, the use of either

procedure would not be justified solely to increase the fatigue strength of the transverse butt welds.

Review of Past and Present Fatigue Tests of Transverse Butt Welds with the Reinforcement Off

(*a*) *Welds Tested on a Zero-Tension Cycle:* The results of the limited number of tests of welds with the reinforcement removed are summarized in Table 7 and in Fig. 11. All of the welds, with the exception of the E7016 welds of the 1953–54 series, had approximately the same average fatigue strength corresponding to failure at 2,000,000 cycles. However, there was a large variation in the average fatigue strengths corresponding to failure at 100,000 cycles. The differences in the behavior of similarly prepared joints is so extreme that no attempt will be made to compare the results for failure at 100,000 cycles. The specimens with a high-temperature stress-relief treatment had about the same average fatigue strength as the specimens without heat treatment, although the stress-relieved specimens had results which were generally in the high range of the scatter band from the specimens without the heat treatment.

Removal of the weld reinforcement has generally resulted in an increase in the fatigue strength. For the welds produced with the E6010 and the E6012 electrodes, the zero-tension average fatigue strengths, given in Table 7, are increased about 20% for failure at 2,000,000 cycles. For failure at 100,000 cycles, the results vary widely, although improvement (from 0 to 50%) generally results with removal of the weld reinforcement. In contrast, the fatigue strength of the E7016 welds is increased about 20% for failure at 2,000,000 cycles, but is decreased about 6% for failure at 100,000 cycles.

(*b*) *Welds Tested on a Tension = Compression Cycle:* Only a limited number of tension = compression fatigue tests were made of specimens with the weld reinforcement removed. The overlapping of the scatter bands in the *SN* diagram of Fig. 11 indicates that the specimens subjected to a 1200° F stress-relief treatment behaved about the same as the specimens without heat treatment. The average fatigue strengths, given in Table 7, indicate that the E6010 welds are somewhat stronger than the welds deposited automatically. Generally, removal of the weld reinforcement increased the fatigue strength of the transverse butt welds tested on a tension = compression cycle from 10 to 40%.

Review of Past Fatigue Tests of Transverse Butt Welds in Silicon Steel and in Low-Alloy, High-Tensile Steel

Scope of Investigation

Only a very limited number of fatigue tests have been made of transverse butt welds in structural steels other than plain carbon ASTM A7 steels. Two series of fatigue tests have been conducted of transverse butt-welded joints in silicon steel and three series of tests of low-alloy, high-tensile steels. One additional series of tests has been made of transverse butt-welded

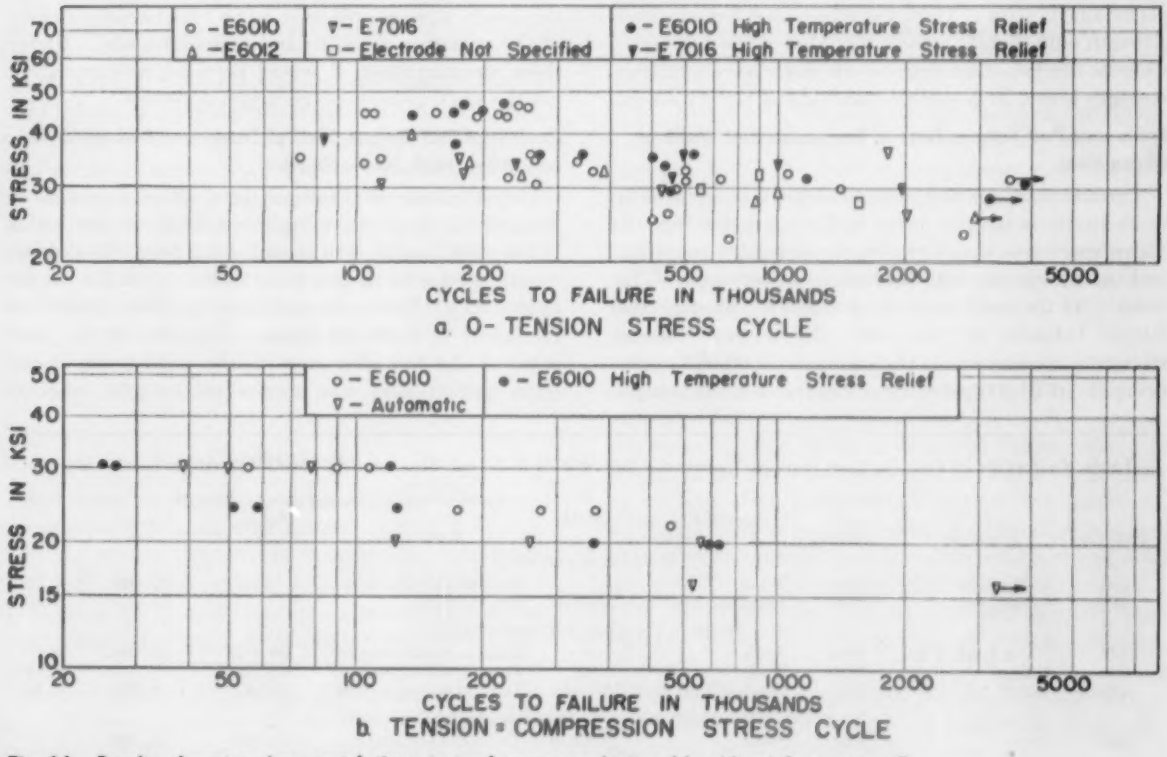


Fig. 11 Results of past and present fatigue tests of transverse butt welds with reinforcement off

Table 8—Properties of Silicon Steel and Low-Alloy, High-Tensile Steel Used in Past Fatigue Tests of Transverse Butt Welds

Steel	Physical properties: Yield point, psi	Tensile strength, psi	% elongation in 8 in.	Reduction of area, %	Chemical content, %: C	Mn	P	S	Si	Cu	Ni	Cr	Va
Bulletin 310													
Silicon steel	49,800	80,700	25	57	0.30	0.91	0.022	0.027	0.23	..	..	..	..
Bulletin 327													
Low-alloy steel	59,100	78,900	21	62	0.16	1.27	0.022	0.036	0.20	0.03	..	0.02	0.12
Bulletin 350													
Low-alloy steel													
Series 13–18	60,400	79,700	30*	68	0.18	0.96	0.019	0.026	0.15	0.20	0.04	..	0.10
Series 46–48	55,300	76,800	23	61	0.15	1.06	0.014	0.035	..	0.05	0.37	..	0.13

Steel	Stress cycle	Average fatigue strength: $f_{100,000}$, psi	$f_{2,000,000}$, psi	k
Bulletin 310				
Silicon steel	Zero-tension	...	35,800†	0.10
Bulletin 327				
Low-alloy steel	Tension = compression	35,300†	26,400†	0.10

* In 2 in.
† Mill scale on.

joints connecting an A7 steel to a low-alloy, high-tensile steel.

The chemical analyses and the physical properties of the steels used in the past tests are presented in Table 8. The data in this table indicate that the ductility and the tensile strength of the two steels are about the same, but the yield point of the low-alloy, high-tensile steels is greater than that of the silicon steel. If one assumes that the tension = compression fatigue strength is 65% of the zero-tension value, the fatigue strength corresponding to failure at 2,000,000 cycles for the low-alloy, high-tensile steel would be about 41,000 psi for a zero-tension cycle, compared to 36,000 psi for silicon steel. Thus, the silicon steel has a fatigue strength only slightly greater than that of the A7 steels, whereas the low-alloy, high-tensile steels have a fatigue strength about 20% greater than that of the A7 steels.

Review of Past Fatigue Tests of Transverse Butt Welds in Silicon Steel

The results of the fatigue tests of the transverse butt welds in silicon steel are given in Table 9 and in Fig. 12. Three specimens were tested in the as-welded condition and three with the weld reinforcement removed. The removal of the weld reinforcement did not improve the fatigue behavior of the joint, the average fatigue strengths corresponding to failure at 2,000,000 cycles being about 23,000 psi. The comparable welds in plain carbon A7 steels, summarized in Table 7, had average zero-tension fatigue strengths corresponding to failure at 2,000,000 cycles which ranged from 17,000 to 24,000 psi in the as-welded condition, and from 26,500 to 29,000 psi with the weld reinforcement off. Thus, the butt welds in silicon steel have average fatigue strengths which are equal to or less than those of butt welds in plain carbon steel.

The ratio of the yield point of the silicon steel to that of the plain carbon A7 steels was approximately 1.4, whereas the ratio between their fatigue strengths was approximately 1.0. Therefore, for silicon steel welded structures which must withstand repeated loadings, the design stresses will have to be based on the ability of the structure to withstand repeated loads. Under these circumstances, it would be more economical to use the less expensive plain carbon A7 steels.

Review of Past Fatigue Tests of Transverse Butt Welds in Low-Alloy, High-Tensile Steels

Only three series of fatigue tests, all on a tension = compression cycle, have been conducted of butt welds in low-alloy steels. For these limited tests, the average fatigue strengths ranged from 23,000 to 26,400 psi for failure at 100,000 cycles and from 15,400 to 18,000 psi for failure at 2,000,000 cycles. The ratio of the yield point of the low-alloy steel to the yield point of the plain carbon steel was approximately 1.65, whereas

Table 9—Results of Past Fatigue Tests of Transverse Butt Welds in Silicon Steel and in Low-Alloy, High-Tensile Steels

Bulletin	Electrode	Position of welding	Special Pre- or Postweld treatments	Average fatigue strength: Stress cycle	$f_{100,000}$, psi	$f_{2,000,000}$, psi	k
			Welds in silicon steel				
310	C-Mo type	Flat	None	Zero-tension	...	22,800	0.10
310	C-Mo type	Flat	Reinforcement machined off	Zero-tension	...	23,700	0.10
			Welds in low-alloy, high-tensile steel				
327	Navy grade EA	Flat	None	Tension = compression	25,700	15,400	0.17
350	E6010	Flat	None	Tension = compression	23,000	...	0.14
350	E6010	Flat	Ground flush root side only	Tension = compression	26,400	18,000	0.14
			Welds joining carbon steel to low-alloy, high-tensile steel				
350	E6010	Flat	None	Tension = compression	25,800	13,700	0.17

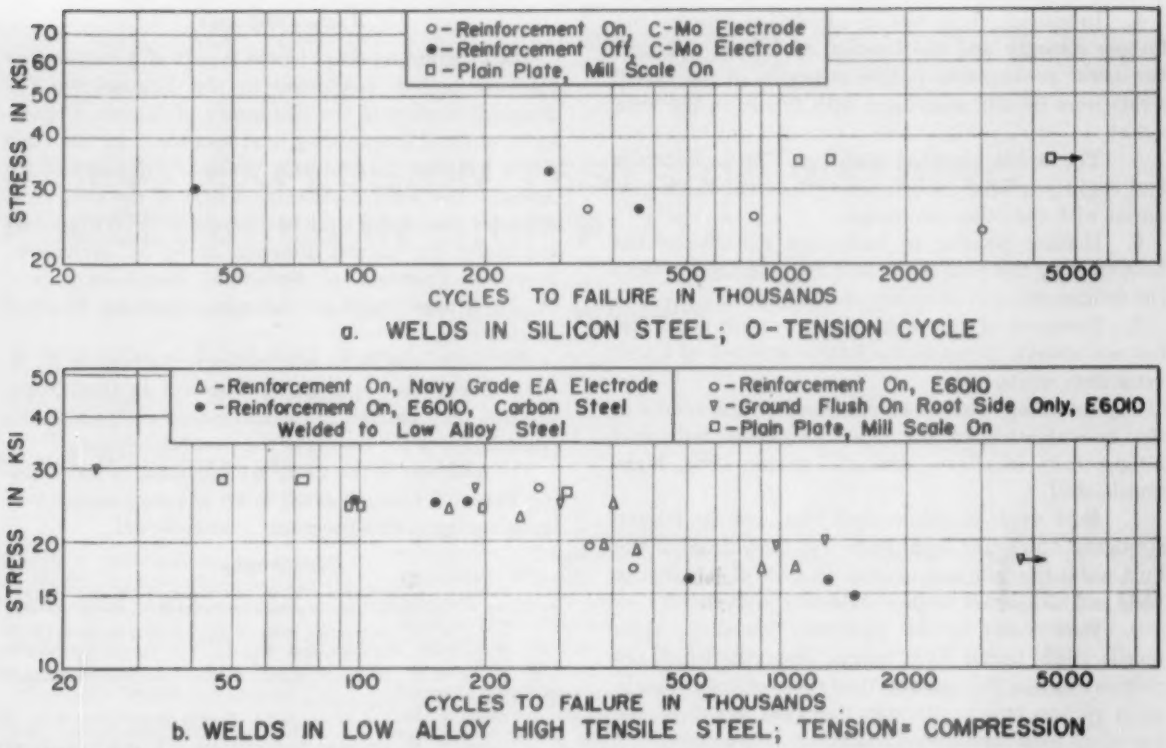


Fig. 12 Results of past fatigue tests of transverse butt welds in silicon steel and in low-alloy, high-tensile steel

the ratio of the fatigue strengths of the butt welds in the same steels was only about 1.2. Thus, as for the silicon steel, the design of a welded structure of low-alloy high-tensile steel subjected to repeated loadings would have to be based on the fatigue strength of the welded joints.

One series of tests was conducted of a transverse butt weld joining a plain carbon steel to a low-alloy, high-tensile steel. For this series of tests, the fatigue strength for failure at 100,000 cycles was about the same as that for the welds in the low-alloy steels, whereas the fatigue strength for failure at 2,000,000 cycles was about that of the welds joining two plain carbon steel plates. Thus, as might be expected, the fatigue strength of welds joining dissimilar steels is probably equal to the fatigue strength of similarly prepared joints in the weaker of the two steels.

Conclusions

The following conclusions are based on the results of the present experimental program.

1. In general, the E7016 longitudinal butt welds, both with the reinforcement on and with the reinforcement removed by grinding, are slightly more resistant to repeated loadings than the E6010 welds, expecially under conditions in which failure occurs after a relatively low number of highly stressed cycles.

2. Removal of the weld reinforcement significantly increases the zero-tension fatigue strength of the longitudinal butt welds produced with both the E6010 and the E7016 electrodes.

3. The results of all of the present tests of transverse butt welds prepared with the E6010 and the E7016 electrodes fell within a narrow scatter band, differences in the fatigue strengths of the two types of weld being relatively small.

4. Removal of the weld reinforcement of the transverse butt welds generally decreased slightly the fatigue strength, with one exception; an increase was obtained in the fatigue strength of the E7016 welds for failures at 2,000,000 cycles.

The following conclusions are based on the results of the re-evaluation of the past and the present fatigue tests of transverse butt welds in plain carbon ASTM A7 steels.

1. A large amount of scatter was encountered in the past fatigue tests of transverse butt welds. For the as-welded joints with welds deposited in the flat position the range in the average zero-tension fatigue strength was from 30,800 to 37,900 psi for failure at 100,000 cycles and from 21,200 to 23,800 psi for failure at 2,000,000 cycles. Individual butt-weld specimens might have a tension = compression fatigue strength as low as 9000 psi for failure at 2,000,000 cycles.

2. Generally, the tension = compression fatigue strength is 60 to 70% of the zero-tension fatigue strength.

3. The welds deposited in the flat position have a significantly greater fatigue strength than those deposited in the horizontal or the vertical positions.

4. In general, there was no correlation between the fatigue strength and the location of failure, although the lower zero-tension fatigue strengths of the E6010 welds were usually associated with failure in the weld metal.

5. The welds prepared with the E7016 electrodes had slightly greater fatigue strengths than those produced with the other electrodes.

6. Neither peening of each pass nor stress-relief heat treating the completed weld consistently increases the fatigue strength of transverse butt welds.

7. Removal of the weld reinforcement generally, but not always, increases the fatigue strength of transverse butt welds.

The following conclusions are based on the results of the re-evaluation of the past transverse butt-weld fatigue tests in silicon steel and in low-alloy, high-tensile steel.

1. Butt welds in silicon steel have average fatigue strengths which are equal to or less than those of the butt welds in plain carbon steel, in spite of the greater yield and ultimate strengths of the silicon steel.

2. Butt welds in the particular low-alloy, high-tensile steels tested have fatigue strengths which are only as much as 20% greater than those of butt welds in plain carbon steels, although the yield point of the low-alloy, high-tensile steel was about 65% greater.

3. A transverse butt weld joining a plain carbon steel to a low-alloy, high-tensile steel is likely to have a fatigue strength equal to that of a similarly prepared joint in plain carbon steel.

Acknowledgments

The program reported herein is part of a cooperative research project conducted in the Engineering Experiment Station of the University of Illinois, Department of Civil Engineering, and sponsored by the Ohio River Division Laboratories, Corps of Engineers, U. S. Army. The work constitutes a part of the structural research program of the Department of Civil Engineering under the general direction of N. M. Newmark, Research Professor of Structural Engineering, and W. H. Munse, Research Associate Professor of Civil Engineering.

The authors wish to acknowledge the help of R. B. Matthiesen, former Research Assistant in Civil Engineering, who assisted in the laboratory work and in the compilation of the results of the past fatigue tests.

The members of the Fatigue Committee of the Welding Research Council acted in an advisory capacity in the planning of this program.

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RESEARCH NEWS

(*Continued from page 82-s*)

Summary Report of Contact Resistance Subcommittee—Welding Research Council

Contact between two metallic surfaces is never uniform over the entire apparent contact area. Actual contact occurs only at small subareas and these may be few in number. This physical phenomena gives rise to Contact Resistance.

Dr. Kouwenhoven, Johns Hopkins University, and his associates have been studying electrical contacts, and have found that contact resistance may be divided into two components. One, called the interface resistance of the contact, which is affected by surface films, by temperature, by contact pressure and other factors, and two, the spreading resistance which results from the constricting action on the current flow of the small subareas in actual electrical contact. The spreading resistance was found to be of considerable magnitude; and, in many cases, it represents the major contribution to the resistance of a contact. A very important development has resulted from this study—a simple method was found for substantially reducing the magnitude of the spreading resistance component. This consists only in subdividing the contact area into small subareas spaced uniformly over the apparent contact area. This work, after a lapse of time, will be continued with the object of making it possible to accurately predict the electrical resistance of a contact, and to demonstrate to industry how this method of reducing contact resistance can be readily applied.

The results of this work are of great significance to the entire electrical industry. In normally prepared contacts the spreading resistance is larger than the interface resistance. The resistance of contacts can therefore be substantially reduced by applying the method developed during this study. This method is presently being used by a major manufacturer of electric resistance welding machines to reduce and control the electrical resistance of contacts in the secondary circuit of spot and seam welders. It may be profitably applied to such diverse items as joints in busbars, contacts on disconnect switches, circuit breakers and magnetic contactors, relay contacts and collector rings.

A thorough understanding of the laws of contact resistance will bring about improvements in the consistency and quality of resistance welds. It is probable that this program will bring about important engineering and economic gains in the entire electrical industry.

(*Research News continued on page 104-s*)

DIRECT EXPLOSION TESTS OF WELDING PROCEDURES IN SHIP PLATE

Report on investigation of performance of semikilled carbon steel ABS Class B and rimmed steel ABS Class A under direct explosion test

BY G. S. MIKHALAPOV AND W. A. SNELLING

Introduction

A series of investigations,[1] sponsored by the Bureau of Ships, Department of the Navy, revealed considerable difference in performance of welded alloy steel plate when subjected to the system of triaxial stresses believed to exist in the Direct Explosion Test. The Ship Structure Committee became interested in determining whether corresponding differences in performance would not be found in low-carbon steel plate used for the construction of merchant marine vessels. The Committee was particularly interested in determining whether differences in welding procedure would not result in a marked difference in performance.

Accordingly, the Ship Structure Committee sponsored an investigation[2] wherein two heats, one of fully killed ABS Grade C and the other semikilled ABS Grade B, both 1 in. thick, were welded with different welding procedures and subjected to Direct Explosion Tests. The principal result of this investigation indicated a marked improvement in performance of fully killed steel when welded with low-hydrogen electrodes over the performance of the same steel when welded with cellulose type electrodes. The difference in performance of semikilled steel when welded with the two respective grades of electrodes was less pronounced, the net effect being to approximate the performance of killed steel when welded with cellulose type electrodes. Although considerable scatter was observed to exist in the performance of semikilled steel plates welded with low-hydrogen electrodes, even the specimens exhibiting the poorest performance still appeared to maintain a substantial, although not spectacular, superiority over the plates welded with cellulose type electrodes.

Accordingly, it was decided that an additional investigation should be conducted to determine the degree of magnitude of improvement of structural performance which the use of low-hydrogen electrodes produced in semikilled steel and, if possible, to establish whether it was of real significance. In addition, a brief investigation of the performance of rimmed steels under the Direct Explosion Test was also undertaken.

However, part way through the investigation it became apparent that performance of a single heat of semikilled steel was not uniform but varied very considerably depending on the particular slab and even plate used. As a result, a secondary objective of the investigation developed, and an attempt was made to establish the degree of variation of performance which can exist within one heat of steel and to correlate, if possible, this variation with conventional notched sensitivity tests, such as Charpy impact and Navy tear tests.

An additional original objective of this investigation was a comparison of performance evaluation by Direct Explosion Test with performance evaluation by the Stand-off (Explosion Bulge) Test as developed by the Naval Research Laboratory. However, because of the difference in performance existing between different plates of the heat of steel purchased, the results of this comparison appear to be somewhat inconclusive.

Method of Testing

The Direct Explosion Test has been described in a number of previous reports.[1, 3] It will be remembered that the test consists of subjecting a number of identical specimens to a blow produced by an explosion of a cylindrical charge of an explosive powder packed to a desired density. The magnitude of each charge is progressively increased until an energy value is reached which just fractures a specimen. The extent of deformation of the specimen subjected to the explosion of a charge just below the minimum charge to fracture is noted and provides an indication of the maximum deformation the plate tested can sustain under the test condition. Specimen failure is said to have occurred when the total length of all fractures exceeds 18 in. (Actually, in the present investigation the overwhelming majority of plates which fractured at all fractured into several pieces.)

As stated above, two grades of ship plate were procured, ABS Class B semikilled steel, and ABS Class A* rimmed

* Class A composition and strength specification rolled to 3/4 in. thickness.

Table 1—Legend—Plate Code No.

Steel designation	*Code No.*	*Mill*	*Heat No.*	*Slab No.*	*Ingot No.*	*Cut No.*	*Plate*
AR	1	Carnegie-Illinois	73U399	123519	2	2	A
AR	2	Carnegie-Illinois	73U399	123519	2	2	B
AR	3	Carnegie-Illinois	73U399	123520	2	1	A
AR	4	Carnegie-Illinois	73U399	123522	3	1	B
AR	5	Carnegie-Illinois	73U399	123523	4	2	A
AR	6	Carnegie-Illinois	73U399	123523	4	2	B
AR	7	Carnegie-Illinois	73U399	123523	4	2	C
AR	8	Carnegie-Illinois	73U399	123524	4	1	A
AR	9	Carnegie-Illinois	73U399	123524	4	1	B
ARX	10	Carnegie-Illinois	73U399	123527	4	1	A
AT	11	Lukens	16445				A & B

G. S. Mikhalapov and W. A. Snelling are with the Coast Metals, Inc., and E. A. Thorne Enterprise, Inc., respectively.

The investigation described in this paper was supported by the Ship Structure Committee as part of its research program. The work was performed under the terms of Contract NObs-2386 between the Bureau of Ships, Department of the Navy, and the Metallurgical Research and Development Co.

The opinions expressed herein are those of the authors and do not necessarily represent the views of the Ship Structure Committee or its member agencies.

Table 2—Chemical Composition and Mechanical Properties of Specimen Steels

Steel Designation	Mfgr.	Heat No.	Deoxidation	Thickness	LADLE ANALYSIS C	Mn	P	S	Cu	Ni	Cr	Si	Plate Code	CHECK ANALYSIS C	Mn	P	S	Cu	Ni	Cr	Si	MECHANICAL PROPERTIES Yield Point	Tens. Str.	Elong. 2"
AB	C. Ill	730399	S.K.	1"	.17	.72	.018	.036					2	.19	.80	.014	.030	.04	.02	.02	.05	33500	57800	43‡
													4	.21	.81	.017	.038	.04	.02	.02	.06	34600	62400	41‡
													7	.20	.81	.017	.035	.03	.02	.02	.05	34300	59000	42‡
													8	.19	.80	.017	.034	.04	.02	.02	.05	34200	61900	41‡
													9	.21	.78	.017	.034	.04	.02	.02	.05	33500	61300	41‡
ABX	C. Ill	730399	S.K.	3/4"	.17	.72	.018	.036																
AT	Lukens	16445	Rim	3/4"	.27	.47	.017	.037	.30	.10	.07‡	--										*39400	68100	24‡‡
																						**38200	64300	26‡‡

NOTE: Check analyses and mechanical property data for plate codes 2, 4, 7, 8 and 9 are as reported in "Report of Investigation on the Notch-Sensitivity Characteristics and Other Properties of AB8, Class B, Steel Plate for Explosion Test Program under Ship Structure Committee - Lab. Project 4936-90, Parts 1 and 2, Final Report, NS 011-043 and NS 011-084" 3 August 1953, by the Material Laboratory, New York Naval Shipyard, Brooklyn 1, New York.

* Transverse

** Longitudinal

‡ Elongation in 8 inches

steel. AB8 Class B was procured in both 1 in. and 3/4 in. thickness, whereas Class A was procured in 3/4 in. thickness. The plate identification for these steels is given in Table 1, and the mechanical properties and typical analyses are shown in Table 2.

A complete performance record covering a temperature range of 70 to −90° F was obtained for unwelded or prime plate, whereas most of the comparisons between the performance of plates welded with different procedures were conducted at 10 and 32° F.

The majority of welds were made with Navy Grade 180 electrodes and with Class E6010 electrodes. Because one of the original objectives of the investigation was the determination of the optimum performance that could be expected from a semikilled or rimmed steel plate as a result of a specific welding procedure, several additional welding procedures were tried. These included use of Navy Grade 230 electrode, Unionmelt process with No. 36 and No. 40 rods, and Aircomatic welding process with two grades of welding wire. In addition, 400° F preheat and 1150° F thermal stress relief were used on both Grade 180 and Class E6010 electrode welded joints.

1. *Manual weld:* 60-deg double-V, 5/32-in. root opening, 0 root face, root pass made with 5/32-in. diam electrode, chipped out to sound metal and welded with three passes on each side, using 1/4-in. diam electrode. A total of seven passes.

2. *Submerged arc weld:* 90-deg double-V, 1/4-in. root face, 0 root opening, submerged arc welded (using Unionmelt No. 20 Flux) with two passes of 1/4-in. electrode, one pass for each side.

Preheat and interpass temperature of 70° F was used in all cases except in case of Grade 180 electrode where a number of specimens were prepared with 200° preheat and interpass temperature and, of course, in the case of specimens subjected to special weld treatments.

Two sources of welding facilities were used, one the Baldwin-Lima-Hamilton Corp., and the other, the Philadelphia Naval Shipyard. When it became apparent that the performance of supposedly identical specimens made at the two facilities did not agree, an attempt was made to check the possibility of the variations in welding procedures between the two sources by having the Philadelphia Naval Shipyard make welds on specimens prepared from the steel plate used for some of the Baldwin specimens. The results of tests of these specimens showed similar performance, and since startling differences in performance of specimens made from two different unwelded plates were also observed, no further attempt to compare the quality of welding of the two sources was made.

As soon as the difference in performance of unwelded plate was established, a review of all available steel plate of the heat purchased was made. In general, it was found that each plate was identified as belonging to a certain slab, ingot and cut. A slab number appeared to identify a

Table 3—Results of Charpy V-Notch and Navy Tear Tests on Steel AR

Plate Code No.	*Location in plate*	*Tear test transition temperature, ° F*	*Charpy V 15 ft-lb transition temperature, ° F*
2	End	90	24
4	End	80	17
	End*	..	30
	Center	90	19
	Opposite end	70	26
5	Middle	..	27
	End	..	28
7	(Unknown)	..	25
	End	90	23
	Opposite end	100	22
8	End	90	18
	Center	100	16
	Center*	..	30
	Opposite end	90	22
9	End	90	20
	Center	120	20
	Center*	..	35
	Opposite end	110	22

NOTE: All results except those marked with an asterisk as reported in "Report of Investigation on the Notch-Sensitivity Characteristics and Other Properties of AB8, Class B, Steel Plate for Explosion Test Program under Ship Structure Committee—Lab. Project 4936-90, Parts 1 and 2, Final Report, NS 011-043 and NS 011-084," Aug. 3, 1953; and Part 3 dated Nov. 30, 1953, by the Material Laboratory, New York Naval Shipyard, Brooklyn 1, N. Y.

* Results marked with asterisk obtained by Naval Research Laboratory.

specific cut of a specific ingot; thus slab No. 123520 is the first cut of ingot No. 2, whereas slab No. 123519 is the second cut of the same ingot. Similarly, slab No. 123524 was the first cut of ingot No. 4, whereas slab No. 123523 was the second cut of the same ingot. However, three plates, 73 in. by 220 in. in length, were rolled from each slab; and since these were not identified separately by the mill, they were given arbitrary designations of A, B and C.

The available identification of the steel plate used is given in Table 1 and is referred to hereinafter by the Code designation given in this table.

The steel mill was unable to provide any further identification of the plates shipped nor was it able to advance any theories as to why a difference in their performance could be expected.

Complete mechanical tests, including Charpy impact and Navy tear tests, were originally planned for the identification of the heat used. Unfortunately, these tests were planned and completed before the difference in individual plate performance was detected by the Direct Explosion Test; and accordingly, a complete test record of all the plates tested is not available. However, it will be seen from Table 3 that Charpy impact tests were made on four of the slabs used.

Discussion of Results

Results of the tests are summarized graphically in Figs. 1 through 8.

Figure 1 shows the performance of the two sets of specimens of unwelded plate made from two different slabs; namely, No. 123519 (Code 1) and No. 123523 (Code 6) of the same heat of 1-in. semi-killed steel. Performance of each specimen is shown by a cross indicating a specimen which did not fail and by an O indicating those which did fail. It becomes immediately apparent that whereas performance of specimens made from slab No. 123519 (Code 1) remain virtually unchanged from room to below −40° F temperature, the performance at 32° F of specimens made from slab No. 123523 (Code 6) dropped drastically and nearly to the level of performance exhibited by slab No. 123519 (Code 1) at −90°. Since no tests were made at temperatures intermediate between −40° and −90° in case of slab No. 123519 (Code 1) steel and between 70 and 32° in case of slab No. 123523 (Code 6), the difference of transition temperature is somewhere between 72 and 160°. Referring to Table 3, it will be seen that the difference in performance of these two slabs as determined by Navy tear tests is virtually nonexistent. However, it must be pointed out that the tear tests and Charpy specimens were not made from the same plate of their respective slabs as were the Direct Explosion specimens. In case of slab No. 123519

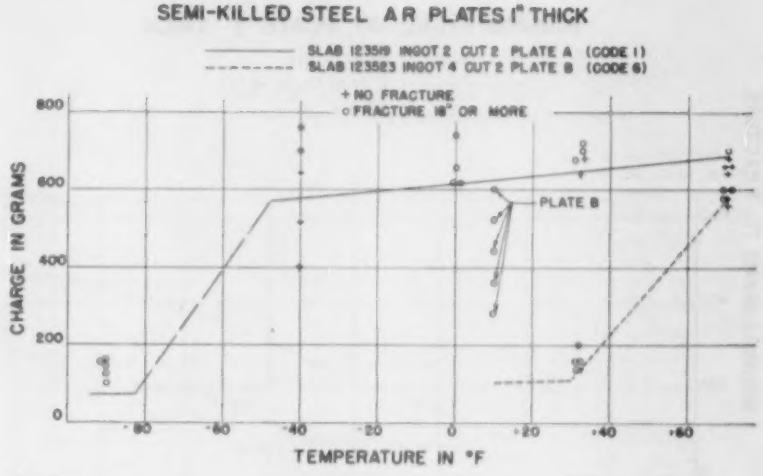

Figure 1

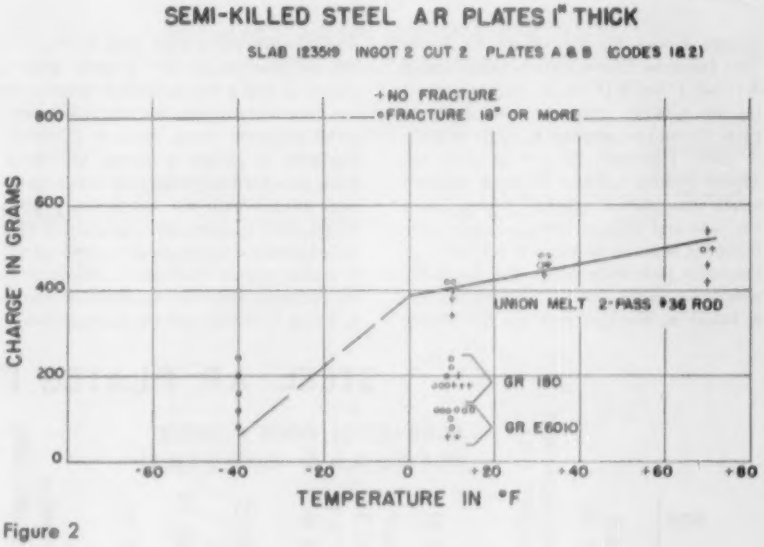

Figure 2

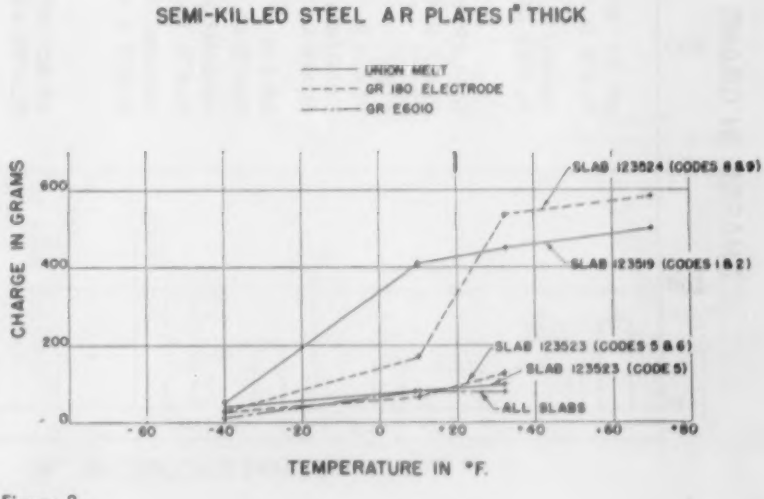

Figure 3

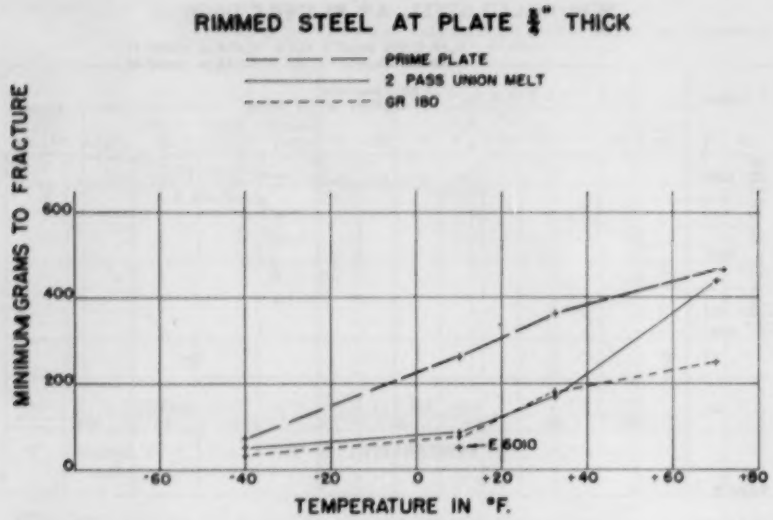

Figure 4

(Codes 1 and 2), the Direct Explosion Test failed to differentiate between plates A (Code 1) and B (Code 2), so that ostensibly the Charpy and tear tests made on plate B could be assumed to apply to plate A also. However, in case of slab No. 123523 (Codes 5, 6 and 7), some evidence exists that plate C (Code 7), from which the tear and Charpy test specimens were taken, is superior to plate B (Code 6), of the same slab from which the Explosion specimens were taken. This indication is based on the fact that the Aircomatic specimens prepared from plate C (Code 7) did not fracture at 32° F until after a charge of 250 g was exceeded, whereas at the same temperature the unwelded specimens prepared from plate B (Code 6) fractured at as low a charge as 140 g. Since it is hard to conjecture that a specimen welded with an Aircomatic process would have performance superior to that of an unwelded specimen of the same plate, it would appear that some difference in the performance of the three plates (Codes 5, 6 and 7) of this slab can be expected.

Figure 2 shows the relative performance of three welding procedures—Unionmelt, Manual Grade E6010 and Manual Grade 180—on plates A and B of slab No. 123519 (Codes 1 and 2, respectively). It will be observed that at 10° F the Unionmelt plate indicates a very appreciable superiority to plates welded with 180 electrodes, which in turn, is very much better than the plate welded with E6010 electrode. With the exception of plates welded with Grade 180 where some scatter was observed, the results are quite consistent.

Figure 3 attempts to indicate the effect of the slab and plate on the performance of specimens welded with Unionmelt, Grade 180, and Class E6010 electrodes. Only the critical points, that is, the points at which fracture occurred, are plotted. It will be seen that performance of specimens made from slab No. 123523 (Codes 5 and 6) is virtually the same regardless of the welding procedure used and is virtually identical to the performance of all slabs (Codes 1, 2, 5 and 8) when welded with Grade E6010 electrode. By comparison, slab No. 123524 (Codes 8 and 9) and No. 123519 (Codes 1 and 2) performed considerably better when welded with Grade 180 and Unionmelt. Based on performance of individual specimens it would appear that, when welded with Grade 180 electrode, Plate A of slab No. 123519 (Code 1) performed better than Plate B of the same slab (Code 2) and both performed better than Plate B of the slab No. 123524 (Code 9).

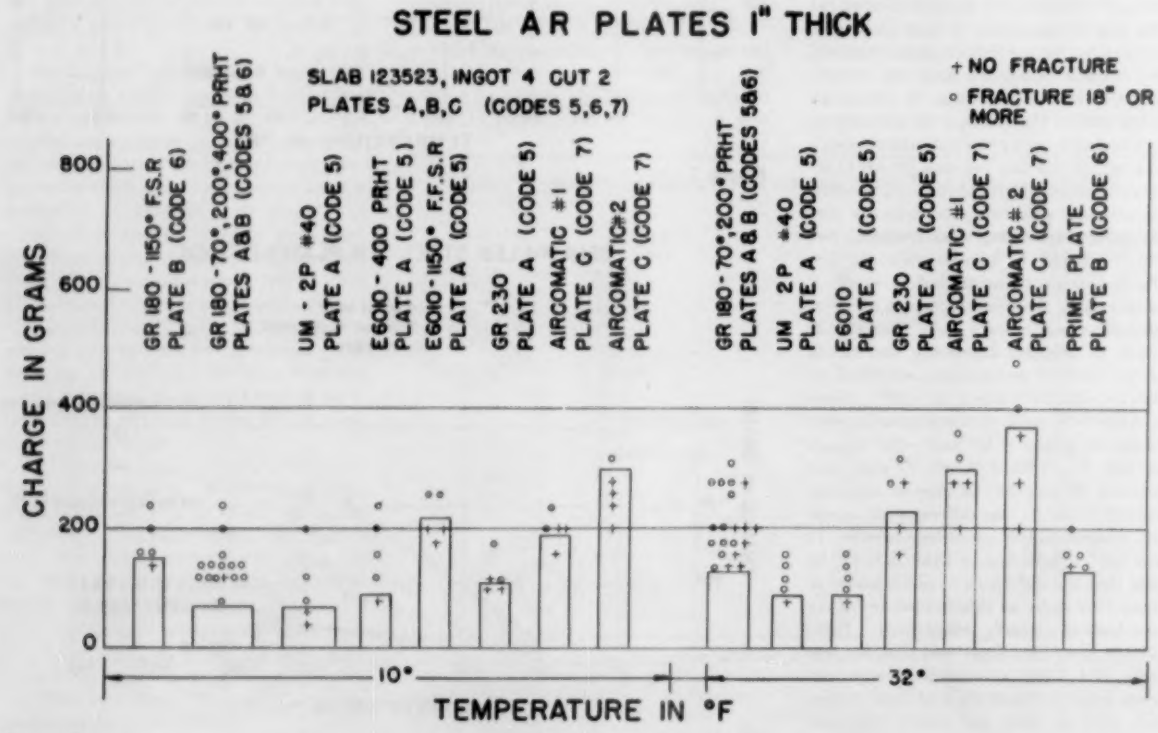
STEEL AR PLATES 1" THICK
SLAB 123523, INGOT 4 CUT 2
PLATES A,B,C (CODES 5,6,7)
+ NO FRACTURE
° FRACTURE 18" OR MORE
CHARGE IN GRAMS
800
600
400
200
0
GR 180 - 150° F.S.R PLATE B (CODE 6)
GR 180 - 70°,200°,400° PRHT PLATES A&B (CODES 5&6)
UM - 2P #40 PLATE A (CODE 5)
E6010 - 400 PRHT PLATE A (CODE 5)
E6010 - 150° F.F.S.R PLATE A (CODE 5)
GR 230 PLATE A (CODE 5)
AIRCOMATIC #1 PLATE C (CODE 7)
AIRCOMATIC#2 PLATE C (CODE 7)
GR 180 - 70°,200° PRHT PLATES A & B (CODES 5&6)
UM 2P #40 PLATE A (CODE 5)
E6010 PLATE A (CODE 5)
GR 230 PLATE A (CODE 5)
AIRCOMATIC #1 PLATE C (CODE 7)
AIRCOMATIC # 2 PLATE C (CODE 7)
PRIME PLATE PLATE B (CODE 6)
10°
32°
TEMPERATURE IN °F

Figure 5

Figure 4 shows the performance of a plate of $^{3}/_{4}$-in. thick ABS Class A steel (Code 11). The performance of the prime plate is considerably inferior to the performance of the best of the two semikilled steel plates (Code 1) but surprisingly enough is superior to the performance of the second semikilled steel plate (Code 6) despite the fact that the latter is $^{1}/_{4}$ in. thicker. It will be noted that at 10° F little difference in the performance of welded plate is encountered regardless of whether the welding is made by Unionmelt, Grade 180 electrode, or Class E6010 electrode. Surprisingly enough, at 70° F the performance of Unionmelt weld is again superior to that of one made with Grade 180 electrode and is very similar to the performance of the prime plate.

Figure 5 shows the summary of all tests conducted at 10 and 32° F of specimens made from slab No. 123523 (Codes 5, 6 and 7) with various welding procedures. At 10° F the performance is uniformly poor with the possible exception of Aircomatic (on Code 7 steel) and E6010 electrodes furnace stress relief annealed at 1150° F. At 32° F Aircomatic (on Code 5 steel) is again the best performer, although improvement over performance of 10° F is not very great, and virtually no improvement is manifested by the other welding procedures tried. It is tempting to make a conclusion that the quality of the plate is so poor that it completely overrides the effect of welding. The superiority of Aircomatic must be tempered by the remembrance that the Aircomatic specimens were prepared from plate C (Code 7) whereas the rest of the specimens which compare unfavorably to the Aircomatic specimens were made from plates A and B (Codes 5 and 6) of the same slab. Furthermore, it must be again remembered that the performance of specimens welded with Aircomatic on plate C (Code 7) is superior to the performance of plate B (Code 6) in prime condition, a fact which is hard to explain except by the presence of inherent differences in plates B (Code 6) and C (Code 7).

Figure 6 summarizes data obtained at all temperatures on slab No. 123524 (Codes 8 and 9) when welded with Grade 180 and E6010 electrodes. On this slab a marked improvement in performance of Grade 180 is apparent at all temperatures above −40°. Unfortunately, incomplete data preclude determination of the exact degree of superiority of Grade 180 over E6010.

Figure 7 presents all data obtained with Unionmelt on slabs No. 123523 (Code 5) and No. 123519 (Code 1). These data have already been presented in condensed form in Fig. 3, and the main purpose of Fig. 7 is to show the lack of scatter of these data.

Figure 8 presents all data taken on rimmed steel and summarized in Fig. 4. There appears to be considerable scatter in performance of plates welded with

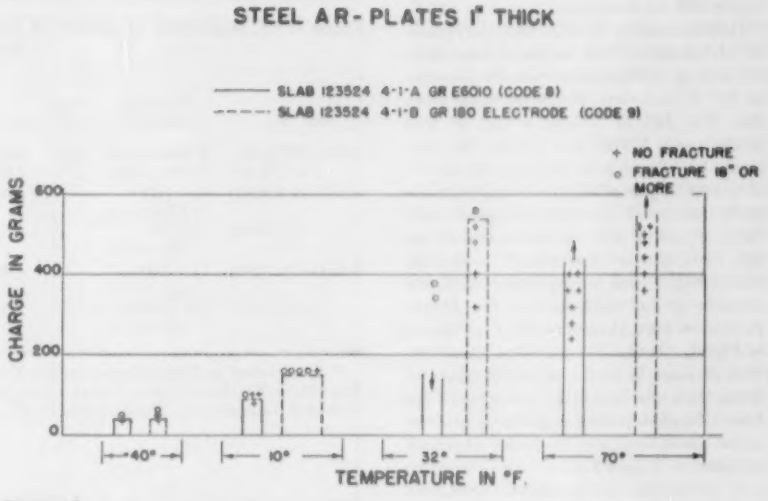

Figure 6

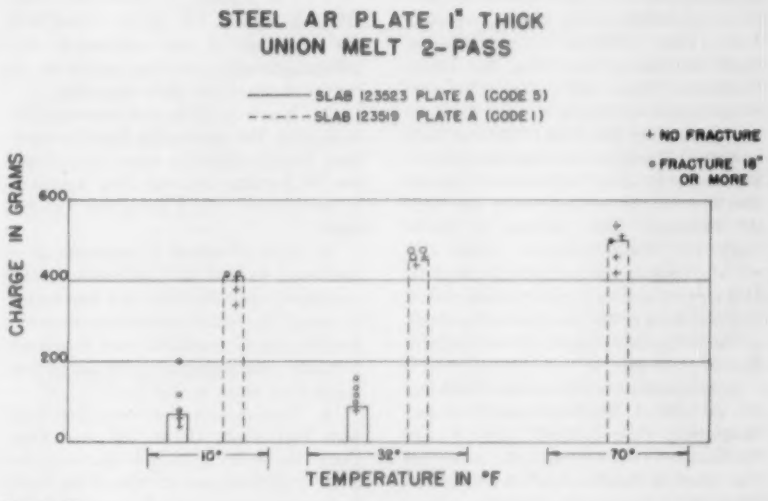

Figure 7

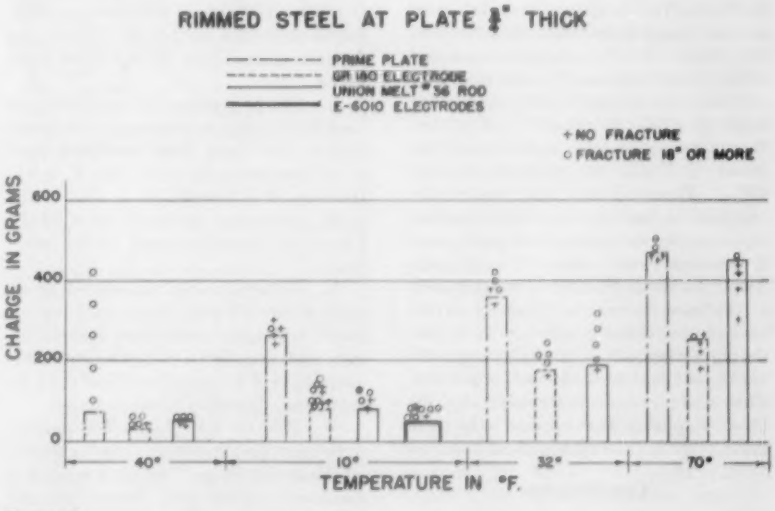

Figure 8

Grade 180 electrodes and tested at 10° F.

It is interesting to note that the Stand-off Explosion Text reveals essentially equivalent performance (except possibly at 40° F) between specimens made from slab No. 123524 (Codes 8 and 9) and welded with E6010 and Grade 180 electrodes.[4] Although as pointed out above, the exact degree of difference between the performance of specimens made with those two electrodes on the same slab has not been clearly determined, a definite superiority of the low-hydrogen electrode appears to be indicated by the Direct Explosion Test, at least at 32° F, as shown in Fig. 6. It can be concluded, therefore, that at least in so far as performance of those two electrodes is concerned, the Direct Explosion Test might be somewhat more discriminatory than the Stand-off (Explosion Bulge) Test.

A collateral investigation conducted with the aid of the Naval Research Laboratory determined the extent of surface strain and reduction in thickness of specimens subjected to the Direct Explosion Test. Table 4 shows the comparison of depth of dish produced by the Direct Explosion Tests with the maximum surface strain on the back of the specimen as measured by the Naval Research Laboratory. It will be observed that there is a reasonably good correlation between the two sets of measurements and that the maximum dish observed in Direct Explosion testing does not exceed 20% surface strain on the back side of the plate. It is also interesting to note that in case of overmatching electrodes the surface strain of the heat-affected zone is nearly double that of the weld.

In comparing the deformation produced by the Direct Explosion and Stand-off (Explosion Bulge) Tests, Pellini and Eschbacher[4] (see Appendix A) point out that whereas the Stand-off or Bulge Test produces a reasonably uniform biaxial strain over nearly the entire specimen, the strain is localized in case of the Direct Explosion Test to a comparatively small circular area 2 in. in radius directly under the charge. It is interesting to note that in the Direct Explosion Test the maximum reduction in thickness in this concentrated area of strain is greater (18%) than the maximum reduction in thickness of the Stand-off Explosion specimens (around 10%). However, the total area under the curve in the reduction of thickness vs. distance from the center of the plate graph is reasonably the same for both tests. Thus, the stress gradient in the direction of thickness is much more severe in the case of the Direct Explosion Test, producing a condition of triaxial tension not unlike that present in the root of a notch. This might explain the reason why the Direct Explosion Text appears to be more discriminating than the Stand-off Test.

Table 4—Comparison of Depth of Dish and Surface Strain* and Reduction of Thickness

Sp. No.	*Welding condition*	*Temp., ° F*	*Charge*	*Depth of dish, in.*	*Max. surface strain, %*	*Surface strain at weld*	*Thickness reduction*
AR-O-26(M-6)	Prime plate	70	600	3.68	19.3	..	..
-27(M-19)	Prime plate		560	3.54	18.8	..	18.8
AR-21-20(M31)	Gr. 180 Electrode		500	3.36	15.0	8.0	..
-27(M38)	Gr. 180 Electrode		520	3.35	15.9	6.0	..
AR-16-20(M51)	Gr. E6010 Electrode		400	3.27	16.0	16.0	..
-14(M57)	Gr. E6010 Electrode		360	2.86	12.0	12.0	..

* As reported in NRL Memorandum Report 190, "Investigation of the Performance of Ship Steel Weldments and Prime Plate Material," by the Metallurgy Division, Naval Research Laboratory, Washington, D. C., dated July 1953.

Conclusions

The following tentative conclusions appear to be justified as a result of this investigation:

1. Performance of unwelded semikilled steel plate, 1-in. thick, rolled from the same heat of steel appears to vary widely, depending on the portion of the heat from which the plate was rolled.

2. Based on the limited investigations conducted, the reasons for the wide variations found within the same heat of steel are not certain, although they appear to be associated with a particular cut and ingot.

3. The difference in performance of specimens welded with different welding procedures appears to be very appreciable in case of the better performing plate of a specific heat of semikilled steel tested and virtually disappears in case of the poorest performing plate of that heat.

4. Performance of welded joints made with Unionmelt, Grade 180, and Class E6010 electrodes appears to line up in this order of performance in case of the better performing plate with Unionmelt being superior to E6010 by a factor of 4 at 10° F.

5. The effect of thermal stress relief at 1150° F is beneficial to welds made with E6010 electrodes on the poor performing portion of the heat of semikilled steel tested.

6. The performance of prime rimmed steel $^3/_4$-in. thick is very much inferior to that of the $^3/_4$-in. thick semikilled steel at all temperatures from 32° F down. However, it is comparable to that of the poorly performing portion (Code 6) of the 1-in. thick semikilled steel of the same heat.

7. Performance of all-welded specimens of rimmed steel, $^3/_4$-in. thick regardless of welding procedure used, is about the same and is similar to that of welded specimens made of the worst portion of the 1-in. thick semikilled steel (Code 6) tested.

8. The Direct Explosion Test appears to be more discriminatory than the Stand-off (Explosion Bulge) Test when applied to specimens welded with Grade 180 and Class E6010 electrodes and prepared from the better portion of the heat of the semikilled steel used, though the evidence is not too conclusive since the data on which it is based are limited.

9. The stress gradient, particularly in direction of thickness produced by the Direct Explosion, appears to be much steeper than that produced by the Stand-off Explosion.

10. The difference in performance of different portions of the heat of the semikilled steel tested, detected by Direct Explosion Test, is not generally apparent on the basis of either the Charpy impact or the Navy tear test conducted.

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3. Mikhalapov, G. S., "Direct Explosion Test to Evaluate Load-Carrying Capacity of Welded Steel Structures," *ASTM Bull.*, No. 172 (February 1951).
4. Pellini, W. S., and Eschbacher, E. W., "Investigation of the Performance of Ship Steel Weldments and Prime Plate Material," NRL Memorandum Report 190, Naval Research Laboratory, Washington, D. C., July 1953.
5. Mikhalapov, G. S., "Evaluation of Ship Welding Procedures by Direct Explosion Testing," Final Report, Ship Structure Committee Report, Serial No. SSC-46 (Aug. 31, 1951).
6. Pellini, W. S., and Eschbacher, E. W., "Investigation of the Performance of Weldments and Prime Plate of ABS-B Steel," Final Report, Part II, Ship Structure Committee Report, Serial No. SSC-78 (June 18, 1954).

APPENDIX A

Strain Studies of Direct Explosion Test Specimens*

The nature of the strain conditions developed in the Explosion Bulge Tests has been described in a previous report.[3]

* This discussion and associated figures are verbatim reproductions of Part II in the report "Investigation of the Performance of Ship Steel Weldments and Prime Plate Material," NRL Memorandum Report 190, by William S. Pellini and Earl W. Eschbacher, July 1953. The permission of the authors for use of this material is appreciated.

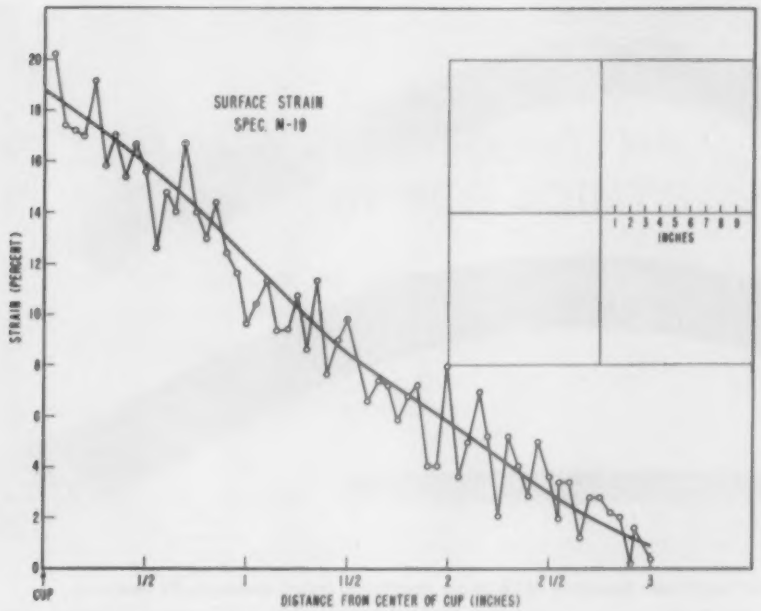

Fig. A-1 Photogrid strain data for prime plate direct explosion test specimen M19. Test conditions —560 Gm of explosive at 70° F

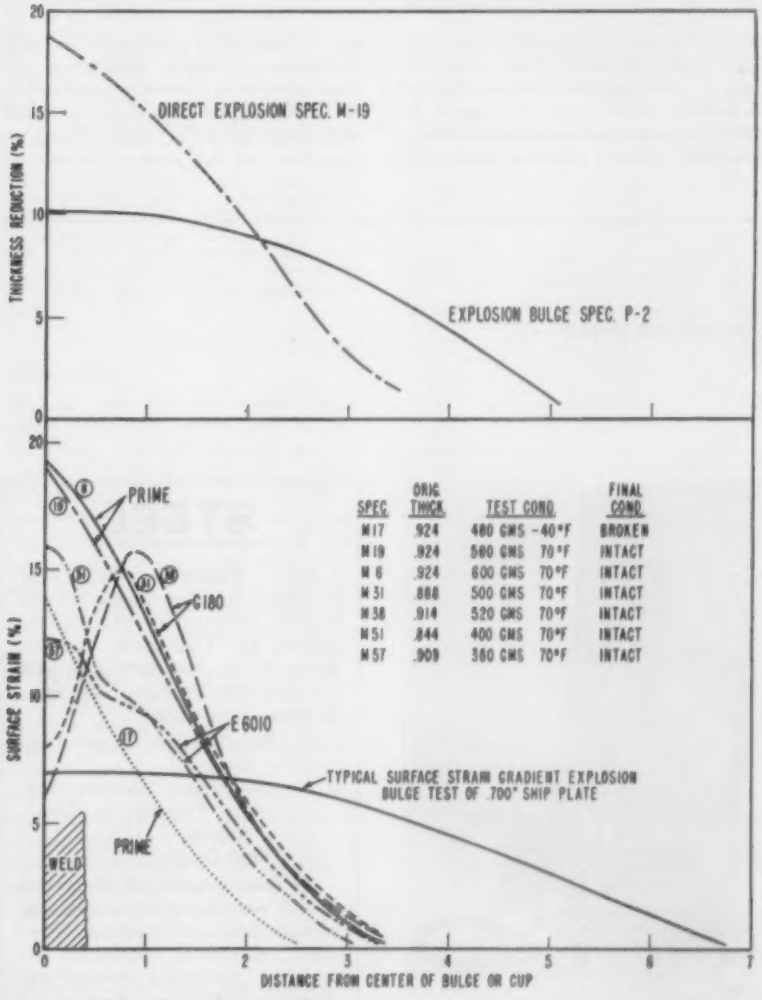
DIRECT EXPLOSION SPEC. M-19
EXPLOSION BULGE SPEC. P-2
THICKNESS REDUCTION (%)
PRIME
G180
E 6010
PRIME
WELD
TYPICAL SURFACE STRAIN GRADIENT EXPLOSION BULGE TEST OF .700" SHIP PLATE
SURFACE STRAIN (%)
DISTANCE FROM CENTER OF BULGE OR CUP
SPEC | ORIG THICK | TEST COND | FINAL COND.
M17 .924 480 GMS -40°F BROKEN
M19 .924 560 GMS 70°F INTACT
M 6 .924 600 GMS 70°F INTACT
M31 .888 500 GMS 70°F INTACT
M38 .914 520 GMS 70°F INTACT
M51 .844 400 GMS 70°F INTACT
M57 .909 360 GMS 70°F INTACT

Fig. A-2 Comparison of deformation conditions developed in direct explosion and explosion bulge tests

Briefly, a circular area of $1\frac{1}{2}$ to 2 in. radius at the center of the bulge shows essentially uniform strain for a prime plate bulge of 10% or less thickness reduction (approximately a 4-in. deep bulge). This signifies that bending is minimized and a condition approaching simple biaxial straining is developed in this region; also that the strain developed in a weld located at the center of the bulge is not greatly in excess of that of the adjacent plate material. Unless this condition is approached the weld would be tested at the disadvantage of being located in a position of naturally higher strain level than the adjacent plate material.

The Direct Explosion Test method utilizes a 4-in. diam. charge placed in contact with the test plate and therefore produces a condition of concentrated loading. Strain grid studies were conducted to determine the nature of strain conditions developed in Direct Explosion Tests. The plates were surface ground to provide a flat, smooth surface required for photogridding. Figure B-1 presents a typical strain grid record obtained by measuring the stretch of individual 0.050-in. grid squares. Readings were obtained in one radial direction only, as indicated on the figure. Figure B-2 illustrates the results of the various strain determinations for 3 prime plates and four weldments (welds ground flush); a typical surface strain plot for the Explosion Bulge method is presented also. Thickness reduction measurements for specimen M19 (Direct Explosion) and P2 (Explosion Bulge) are shown at the top of Fig. B-2. Figure B-3 shows cross sections of M19 and P2. It is evident from these various figures and plots that the Direct Explosion Tests result in pronounced deformation gradients and bending conditions. Within a 3 in. distance from the center of the Direct Explosion cup the surface strain falls from approximately 20% to essentially nil values and the thickness reduction from approximately 18% to nil values.

Since $E_1 + E_2 = E_3$ (sum of biaxial surface strains (positive) is equal to thickness strain (negative)) as dictated by constancy of volume considerations, it should be expected that simple biaxial straining should be characterized by a thickness reduction equal to the sum of the surface strains. Specimen M19 shows that the thickness reduction is only half the biaxial surface strain total and accordingly that the inner surface must have strained considerably less than the outer surface. In simple terms, pronounced bending conditions must have been developed so as to produce high strains on the outer surfaces and low strains on the

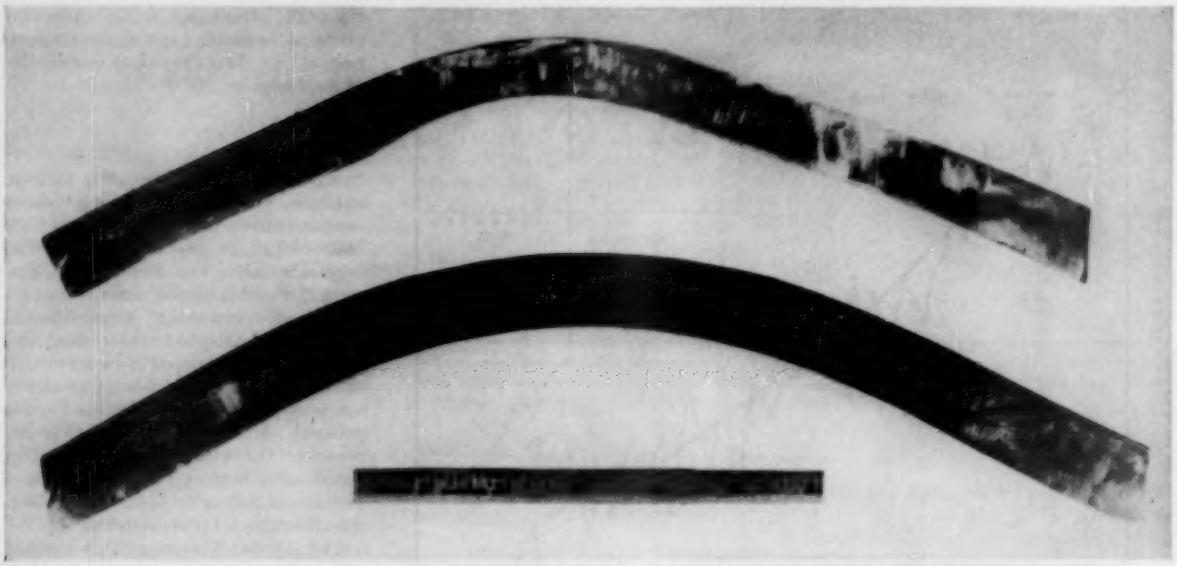

Fig. A-3 Cross sections of specimens: direct explosion specimen M19 (top); explosion bulge specimen P2 (bottom)

inner surface. It is concluded that the stress mechanics resulting from Direct Explosion loading entail highly localized biaxial bending conditions.

The strain plots for the Direct Explosion Test weldments show a strain deconcentration for the high flow strength (overmatching) G180 welds and a strain concentration for the lower flow strength (undermatching) E6010 weld. It should be noted that this effect is obtained only in a transweld direction and that strains (but not stresses) are equivalent in the weld longitudinal direction. Such strain and stress conditions should be expected in biaxial tension irrespective of the degree of bending involved. This subject has been discussed in a previous report.[5]

RESEARCH NEWS

(*Continued from page 96-s*)

Stress Analyzer

For the first time, a portable stress analyzer using the X-ray diffraction method is available for field and plant operations. Known as the "Androscope," it measures the magnitude and sense of residual stresses in metals, plastics and other materials. It transfers practical nondestructive residual stress measuring from the laboratory to the field and plant and is easily operated.

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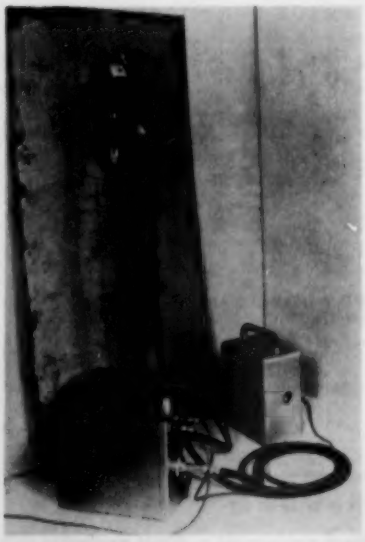

Androscope

STEEL

The WELDING RESEARCH COUNCIL has just issued Bulletin No. 20 consisting of three timely papers by Charles M. Parker, Assistant Vice-President, American Iron and Steel Institute. The titles of these papers are:

1. High-Strength, Low-Alloy Steels
2. Analytical Chemistry Fosters Progress in Steelmaking
3. Steel Quality

All three papers are of interest to the welding industry and are written from a practical viewpoint. Copies of Bulletin No. 20 may be purchased through the American Welding Society at $1.00 per copy.

FILLER-METAL STRENGTHS IN BRAZED COPPER JOINTS

Study of butt and lap brazed joints made with six different filler metals and tested at room, elevated and low temperatures

BY W. H. MUNSE AND D. C. CRAWFORD

SYNOPSIS. This paper summarizes the results of a testing program designed to determine the differences in strength of brazed copper joints made with various filler metals. Specimens fabricated from 1/4-in. electrolytic tough-pitch or deoxidized high-phosphorus copper, and utilizing six representative types of filler metal were included in the study. These filler metals are classified as BAg-1, BAg-6, BAg-8, BCuP-2, BCuP-4 and BCuP-5 under the present AWS-ASTM tentative specification for brazing filler metals.

The test specimens consisted of two types—lap joints and butt joints—and furnish data concerning the shearing strength and tensile strength of the joints. Although the majority of the specimens were tested at room temperature, a number of the tests were conducted at +400 and −321° F and demonstrate the effect of testing temperature on the strength of the joints prepared with the various filler metals.

Introduction

Brazing, one of the eight major welding processes, is defined by the AMERICAN WELDING SOCIETY as, "a group of welding processes wherein coalescence is produced by heating to suitable temperatures above 800° F and by using a nonferrous filler metal, having a melting point below that of the base metal. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction."[1]

The joining of metals by brazing may be further broken down into eight general processes using a variety of base metals and filler metals.[2] However, this paper is concerned with only a very small part of the field of brazing: the torch brazing of copper with two classes of filler metal. This is probably the most common method of brazing in so far as copper is concerned.

A number of factors are found to effect the strength of a brazed joint and must be taken into consideration if sound brazed joints are to be produced.[1, 3] There may, at times, be some tendency to overlook some of these factors because a brazed lap joint is generally prepared with a braze area sufficient to provide a joint strength greater than that of the base metal. However, if a fully sound joint is to be made, joint design, cleaning of the joint surfaces, fluxes, jigging, selection of filler metal, and the method of heating,

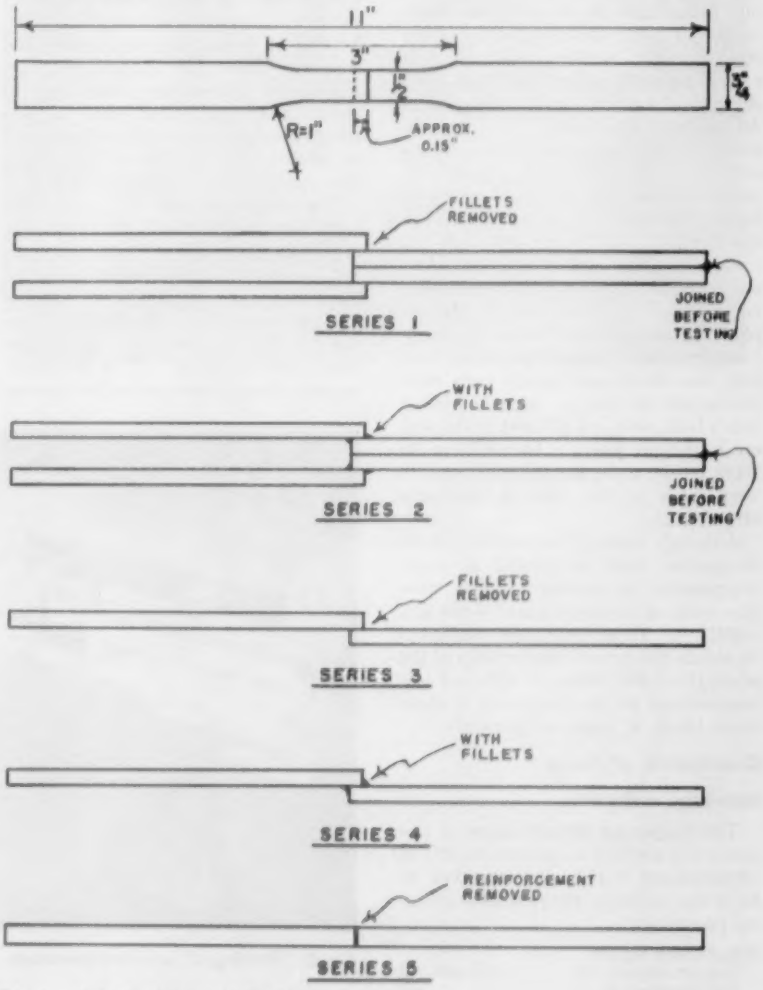

Fig. 1 Details of brazed joints

W. H. Munse and D. C. Crawford are associated with the Structural Research staff at the University of Illinois, Urbana, Ill.

Presented at the Thirty-Fifth AWS National Fall Meeting held in Chicago, Nov. 1–5, 1954.

Table 1—Summary of Filler Metal Properties

AWS-ASTM designation	Chemical composition, % Cu	Ag	Zn	Cd	P	Solidus, temp., ° F	Liquidus, temp., ° F	Brazing temp. range, ° F
BAg-1	15	45	16	24	..	1125	1145	1145–1400
BAg-8	28	72	..	..	..	1435	1435	1435–1650
BAg-6	34	50	16	..	..	1270	1425	1425–1600
BCuP-5	80	15	..	..	5	1185	1500	1300–1500
BCuP-4	87	6	..	..	7	1185	1380	1300–1500
BCuP-2	93	..	..	..	7	1305	1485	1350–1550

are extremely important and should be given careful consideration.[1]

Object and Scope of Investigations

The principal objective of this study was to determine the strength, at various temperatures, of brazed joints in tough-pitch and deoxidized copper when joined with various filler metals.

It is well known that sound brazed joints assembled with a lap of two or three times the thickness of the connected material will develop the full strength of the base metal, and that the critical section of a structure using such a joint will seldom be in the joint itself. However, it may not be necessary to maintain this large lap to obtain failure in the base metal. To study this question, further information is needed concerning the ultimate shearing strength of a brazed lap joint in copper. An attempt has been made, in these tests, to obtain this information. However, to do this it has been necessary to design a joint of such dimensions that failure would always occur in or near the joint.

The investigation has been limited to studies on two types of base metal, using two classes of filler metal: copper-phosphorus and silver.[4] After a suitable brazing procedure and specimen type had been developed, tensile tests were conducted on single- and double-lap joints both with and without fillets, and on butt-type joints. In addition to these tensile tests, metallurgical studies were made of the various specimens after failure.

Although most of the tests of this investigation were conducted at room temperature, a number of tests were also made at temperatures of +400 and −321° F. These tests were conducted to obtain the general relationship of the strength of the joints at high and low temperature to the properties of these same joints at room temperature.

Description of Tests

Description of Materials

The copper for the specimens of this study was certified to conform to ASTM Designations B-152, and reported to have the following physical and chemical properties:

Tough-pitch copper
- Copper content, %.....99.942
- Tensile strength, psi.....31,500
- Elongation in 2 in., %.....50

Deoxidized high-phosphorus copper
- Copper content, %.....99.942
- Tensile strength, psi.....31,600
- Elongation in 2 in., %.....45
- Phosphorus content, %.....0.029

These materials appeared to be of uniform structure, typical of good mill practice. However, the deoxidized copper had a grain size of approximately 0.400 mm in diameter, while the tough-pitch copper had the grain size of approximately 0.040 mm in diameter. Thus, the deoxidized copper had a much larger grain size than did the tough-pitch copper.

The brazing materials (BAg-1, BAg-6, BAg-8, BCuP-2, BCuP-4 and BCuP-5) were selected as being representative of those which would be suitable for the brazing of tough-pitch and deoxidized copper. These filler metals, obtained from three different suppliers, were in the form of $^1/_{16}$-in. diam wire. A summary of the properties of the filler metals as provided in the AWS-ASTM tentative specification[4] is given in Table 1.

The copper-phosphorus (BCuP) filler metals are used primarily for the joining of copper and copper alloys and have self-fluxing properties when used with these materials. Although the range of brazing temperature for the three copper-phosphorus filler metals extends from 1300 to 1550° F, it is recommended that these materials be used with the lowest temperature which will produce a sound joint.

The silver filler metals (BAg classification) are also suitable for joining copper as well as other nonferrous and ferrous metals. For the three silver filler metals selected in this study the brazing temperature is found to range from 1145 to 1650° F. Joints brazed with these materials generally require the use of a flux.

Description of Specimens

Several groups of preliminary tests were conducted to provide a basis for the selection of the type of test specimen. In these tests, the length of lap necessary to insure failure in the joint was determined as well as the details of the brazing procedure necessary to produce sound joints.

On the basis of the results of the various preliminary studies, it was concluded that:

1. In order to obtain failure at the joint of a lap joint specimen in $^1/_4$-in. copper, it is necessary that the lap be no greater than 0.15 in.
2. A nearly direct shear loading can be obtained in a test of a symmetrical specimen, such as was used by Peaslee and Boam.[5] However, it was found to be difficult to obtain consistent results with this type of specimen.
3. The procedures developed for this

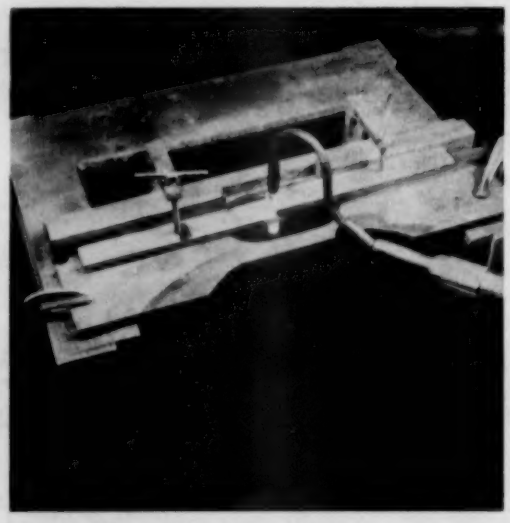

Fig. 2 Brazing of lap joint specimens

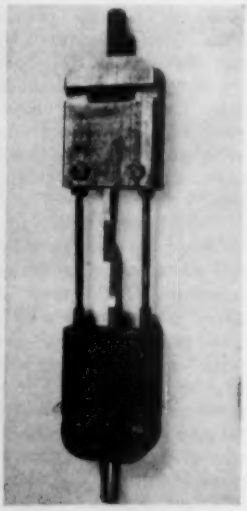

Fig. 3 Test assembly for high- and low-temperature tests

study will provide sound brazed joints in both the lap- and butt-type connections. However, extreme care must be exercised in the clamping and jigging of the specimens.

Based on these studies, specimens of the type shown in Fig. 1 were selected for the program. Strips approximately $^{3}/_{4}$ in. wide, $5\,^{5}/_{8}$ in. long and $^{1}/_{4}$ in. thick were prepared for joining as test specimens. After the specimens had been brazed, the joints were reduced to the $^{1}/_{2}$-in. section shown in the upper part of Fig. 1. For the specimens to be tested without fillets, the laps were next machined to 0.15 in. by cutting off the ends of the strips at the joints. The fillets were removed in this process. In the case of the butt joints, the excess filler metal was removed from the faces and edges of the joint. The last step in the fabrication procedure was the brazing of the two joints to form the double specimens of Series 1 and 2.

Brazing Procedure

Copper is a material which is readily brazed. However, the procedure must be carefully controlled if sound joints are to be obtained. The material must be clean, the clearances carefully controlled, and the positioning or jigging of the materials carefully planned.[6, 7]

To remove the oxides at the areas to be joined, the surfaces were lightly filed and then polished with a 2/0 emery cloth. After the strips were wiped clean with carbon-tetrachloride they were brazed.

In filing and polishing the surfaces of the material for the lap joints, the specimens were oriented so that the scratches would be parallel to the axis of the joint. This permits the filler metal to flow freely through the entire length of the lap. Funk and Udin[8] have pointed out that the flow of the filler metal will be impeded by capillary dams if the clearance is not uniform in the direction of flow.

After the appropriate flux had been applied to the areas to be joined, the copper strips were placed in the brazing jig shown in Fig. 2. The strips were then clamped into position with a lap of 0.15 in. and a clearance of 0.003 in. It should be noted, however, that although a gap of 0.003 in. was set between the copper strips, the distortions which occur in the material as it is heated may change this clearance somewhat.

For the butt joints, only one strip was clamped in the brazing jig. The other strip was butted up to and in line with the clamped strip. This was found to be necessary because of the expansion which takes place in the copper during the heating of the specimen, and the difficulty of presetting a gap to give a joint of 0.002 to 0.003 in. thickness. The procedure of butting the two strips and allowing them to force one another apart as they were heated, was found to produce very consistent and sound joints.

The brazing procedures were fundamentally the same for both the lap and butt joints. A medium light-weight torch with five-hole (68-drill) dual tips was used for the brazing (see Fig. 2). By means of a 2-stage regulator, constant oxygen and acetylene pressures were used throughout the brazing operations. These pressures were 20 psi and 2.5 psi, respectively.

By using a neutral flame with the dual-tip torch and starting the heating of the specimens approximately 2 in. on either side of the joints, it was possible to work the heat uniformly into the joint area, and face-feed the filler metal to produce sound brazed joints. The uniform heating of the material in the vicinity of the joint is thought to be an important factor in obtaining sound brazed joints.

Description of Tests

The tests of the joints were conducted at room temperature, +400 and −321° F. Those at room temperature were tested in a 120,000-lb hydraulic testing machine in a manner similar to that used for standard tension tests. For the tests of the double specimens of

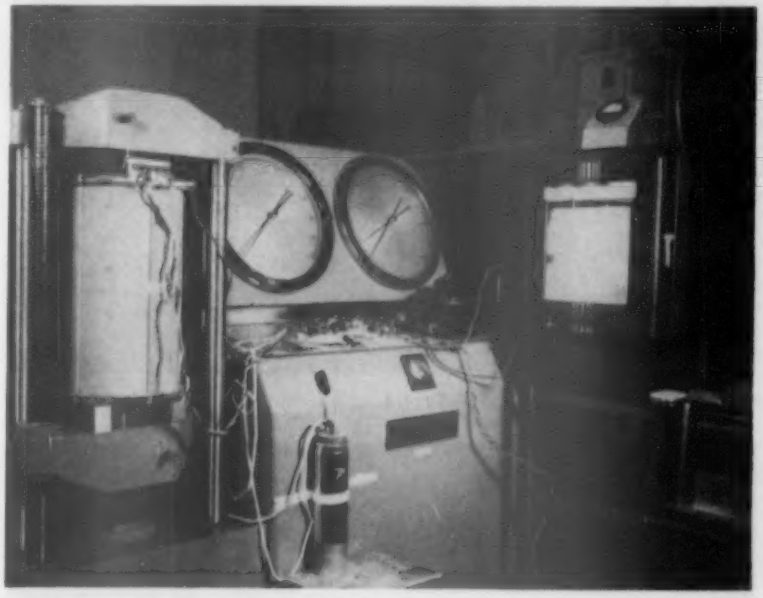

Fig. 4 Apparatus for tests at +400° F

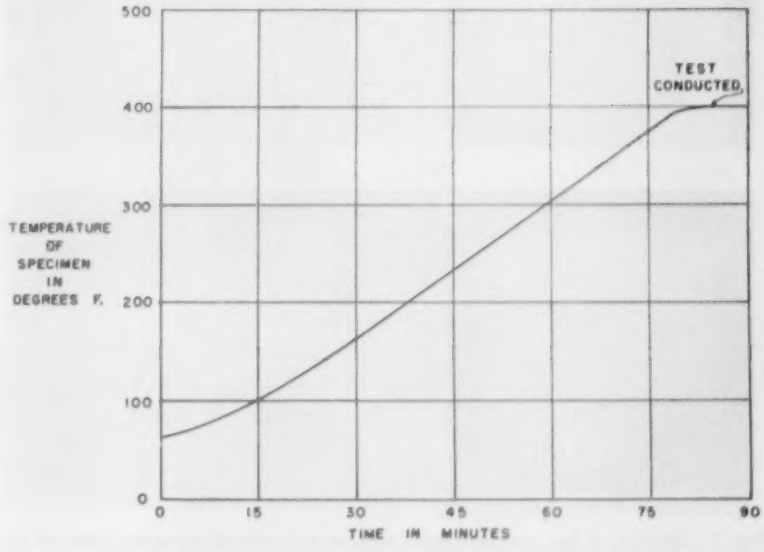

Fig. 5 Typical time-temperature curve for a specimen tested at +400° F

Series 1 and 2, a $^1/_2$-in. spacer bar was placed between the outer strips at the end of the specimen so that the specimen could be gripped tightly in the testing machine. For the tests of the single-lap joint specimens, the jaws at either end of the testing machine were offset $^1/_8$ in. in opposite directions. These offsets placed the load line in the tests directly through the joint. The butt joints of Series 5, since the specimens were in a single plane, could be tested as a standard tension specimen.

To study the effect of high temperature on the strength of the joints, a short series of deoxidized copper specimens without fillets were prepared with BAg-1, BCuP-2 and BCuP-5 filler metals and tested at a temperature of +400° F.

Special pullheads were used for the tests conducted at +400° F. After the specimens had been placed in the pullhead assembly shown in Fig. 3, the entire assembly was placed inside an electric furnace (see Fig. 4).

A continuous record of the temperature was recorded during each test. A sample record is shown in Fig. 5. Approximately 80 min was required to reach the testing temperature; the specimen was then loaded to failure within a period of a few minutes.

The tests at −321° F were conducted in a manner somewhat similar to that used for the specimens tested at +400° F. The specimens were placed in the specimen pullheads shown in Fig. 3, and then the entire assembly placed in the large insulated tank shown in Fig. 6.

To obtain the desired temperature, liquid nitrogen was forced into the open insulated container until the liquid nitrogen completely covered the test assembly. After the level of the liquid nitrogen had been maintained at the top of the container for 10 to 15 min, and specimen had been lowered to a temperature of −321° F, the joint was loaded to failure.

Upon completion of the tensile tests, metallurgical specimens were cut from a number of the fractured joints. These sections, cut transverse to the joint and about midway between the edges of the specimen, were mounted, etched and polished for microscopic examination.

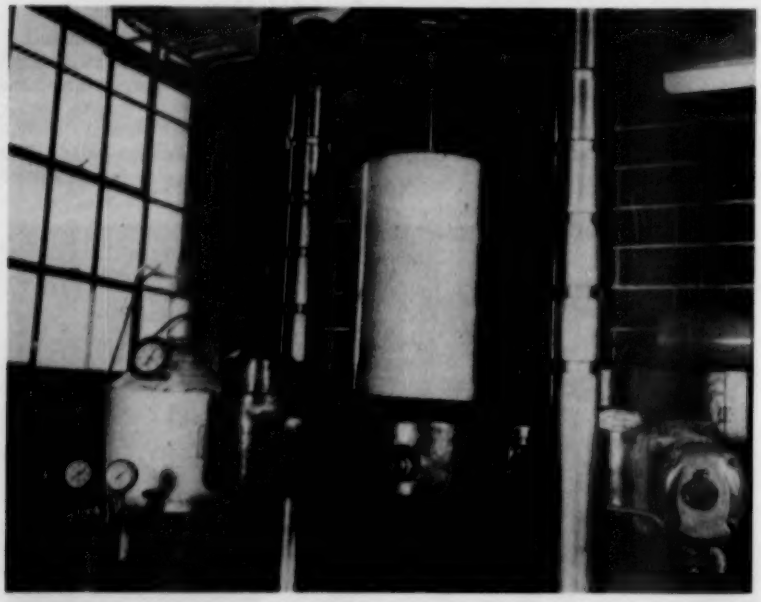

Fig. 6 Apparatus for tests at −321° F

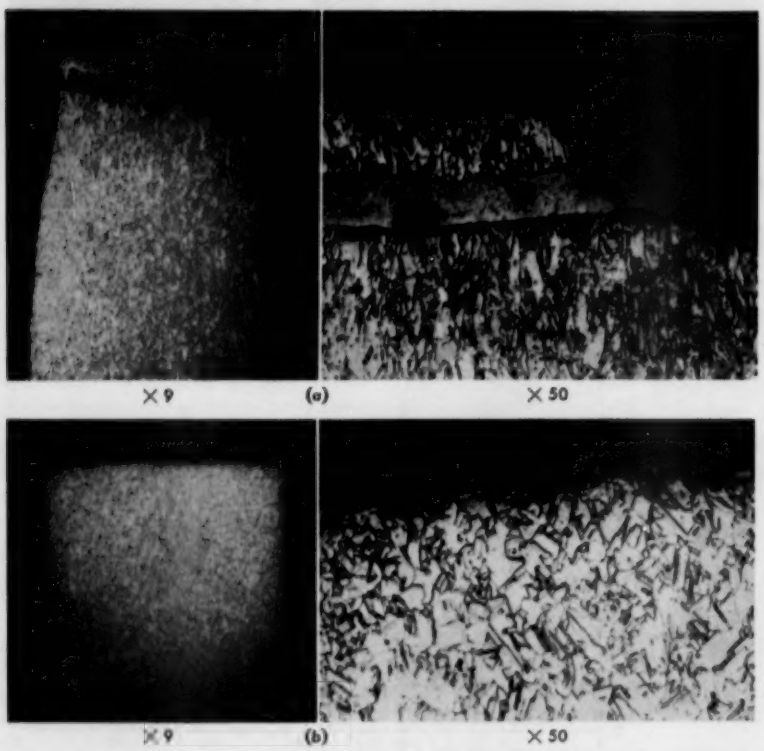

Fig. 7 Sections of fractured brazed butt joints in tough-pitch copper (reduced by 25% in reproduction). (a) BAg-1, filler metal. (b) BCuP-4, filler metal

Results of Tests

The results of the room temperature tests of the lap joints and butt joints are summarized in Tables 2 and 3. In general, the load-deformation characteristics and the ultimate strengths obtained from duplicate tests of each type of joint were quite consistent.

Over-all averages of the strengths obtained for the 5 types of joints are as follows:

Double lap joints without fillets, psi	18,200
Double lap joints with fillets, psi	23,300
Single lap joints without fillets, psi	18,600
Single lap joints with fillets, psi	23,100
Butt joints, psi	26,500

The results of the tests at +400 and −321° F are presented in Table 4. It may be seen that the deoxidized copper joints prepared with three of the filler metals had tensile strengths of about 10,000 to 11,000 psi when tested at +400° F. This is a reduction in strength of approximately 44% from the room temperature strength of the same type joint. Tension coupons of the same base material, when tested at

Table 2—Ultimate Strengths of Lap Joints (Strength, in Psi)

Filler metal	Deoxidized copper — Without fillets	Deoxidized copper — With fillets	Electrolytic copper — Without fillets	Electrolytic copper — With fillets
	Double lap joints			
BAg-1	17,010	22,540	17,960	24,120
BAg-8	18,790	22,030	17,720	21,370
BAg-6	17,150	23,560	19,000	28,040
BCuP-5	19,030	22,430	17,610	19,490
BCuP-4	18,020	25,050	19,080	25,900
BCuP-2	18,600	25,550	18,970	19,320
	Single lap joints			
BAg-1	19,040	23,160	18,060	27,530
BAg-8	17,620	23,060	19,750	22,440
BAg-6	17,610	24,180	18,750	23,890
BCuP-5	17,900	19,790	18,330	23,870
BCuP-4	19,150	24,430	18,000	23,690
BCuP-2	18,640	20,900	20,040	20,480

NOTE: The strengths reported represent the average obtained from tests of duplicate specimens.

Table 3—Ultimate Strengths of Butt Joints (Strengths in Psi)

Filler metal	Deoxidized copper	Electrolytic copper
BAg-1	27,100	21,300
BAg-8	25,400	21,800
BAg-6	30,400	27,700
BCuP-5	27,300	25,500
BCuP-4	27,500	28,100
BCuP-2	31,200	24,900

NOTE: The strengths reported represent the average obtained from tests of duplicate specimens.

+400° F, were found to be only 24% weaker than at room temperature.[9] Thus, the elevated testing temperature had a greater effect on the strength of the brazed joints than it did on the strength of the copper itself.

Table 4—Ultimate Strengths of single-Lap Joints of Deoxidized Copper at Low and High Temperatures (Strengths in Psi)

Filler metal	Strength in psi, at +400° F	Strength in psi at −321° F
BAg-1	9,700	30,100
BAg-8	..	24,700
BAg-6	..	28,000
BCuP-5	10,850	21,900
BCuP-4	..	21,400
BCuP-2	10,700	17,900

NOTE: The average strengths reported represent the average from four tests.

Brazed joints in deoxidized copper and with all six filler metals were also tested at −321° F. The average strengths of these joints ranged from 30,100 psi for the joints with BAg-1 filler metal to 17,900 psi for the joints prepared with BCuP-2. These values are 158 and 97%, respectively, of the room temperature strengths. Therefore, it appears that the effect of the low temperature on the strength of the joints prepared in deoxidized copper varies considerably from one filler metal to the next. And, since the base metal strength at −321° F is about 52,000 psi,[9] none of the joints tested had strengths which were, comparable to the strength of the copper itself at −321° F. except the joints prepared with BAg-1.

Metallurgical Studies

All of the joints showed evidence of good bonding and a narrow zone of interdiffusion at the filler metal-base metal interface. The only evidence of any structural change in the base metal as a result of the joining operation appeared in the butt joints of deoxidized copper. Here a thin layer of fine grains formed adjacent to the joints. This was apparently a result of recrystallization during the heating of the surface which had been cold worked during the preparation of the specimens. It is doubtful, however, that this would influence greatly the mechanical properties of the joints.

Examination of the fractures indicates that the butt joints generally failed at the interface between the filler metal and the base metal (see Figs. 7 and 8). However, the joints in tough-pitch copper prepared with the silver brazing alloys failed in the base metal very near the joint interface. One of the tough-pitch copper specimens brazed with the BAg-1 filler metal exhibited considerable distortion and a shear failure plane running diagonally through the joint and the base metal (see Fig. 7*a*). All of the other fractures in the tough-pitch copper were on a plane parallel to the joint interface.

Only one of the butt joints in deoxidized copper failed in the base metal. This failure was parallel to the joint interface and occurred only after considerable necking had taken place in the joint.

In the case of the lap joints, the failures occurred at the interface or in the base materials for both types of copper (see Figs. 9 and 10). The failures in the base metal were generally located near the joint interface and accompanied by heavy localized deformations. It was noted also that the deformation in those joints which were prepared with the silver base alloy extended through a larger volume of the base metal than in the joints of the other filler metals.

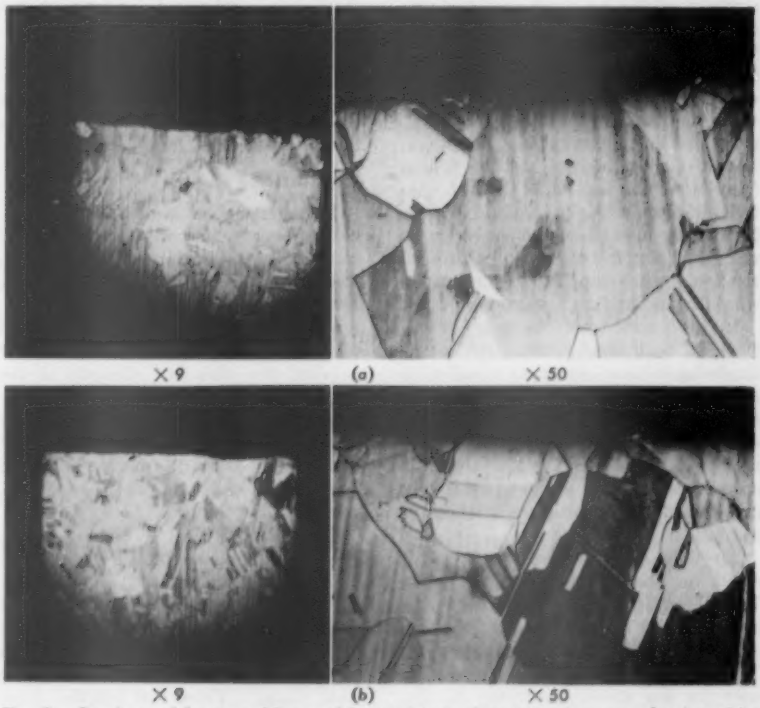

Fig. 8 Sections of fractured brazed butt joints in deoxidized copper (reduced by 25% in reproduction). (*a*) BAg-6, filler metal. (*b*) BCuP-2, filler metal

Discussion of Test Results

The strengths of the deoxidized and tough-pitch copper was found to be very nearly the same for double- and single-lap joints. However, since all of the joints failed in the base metal near the joint interface, these ultimate strengths are for the copper; the strengths of the filler metals are all greater than those of the base metals.

The copper adjacent to the filler metal, based on the results of these tests, had a strength approximately 60% as great as the tensile strength of the base material. Although this strength may approximate the shearing strength of the copper, it must be remembered that the bending in the joints produces a small tensile component also. Thus, the strength of the joints is for a combination of shear and tension on the copper and may be slightly higher than the shearing strength alone.

The butt joints in the deoxidized copper were generally stronger than those in the tough-pitch copper—the joints in the deoxidized copper failed at the interface while the joints in the tough-pitch copper failed in the base metal very near the joint interface. In neither case, however, does the strength represent the ultimate strength of the filler metal, but rather an indication of the bonding of the filler metal to the deoxidized copper and the strength of the tough-pitch copper when brazed with the various filler metals.

The brazing did not seem to effect the strength of the lap joints, but did produce differences in the manner of fracture. In a visual inspection of the fractures, it appears that the deoxidized copper joints failed in the filler metal while the joints in the tough-pitch copper failed in the base metal. However, in the microscopic examination it was found that the lap joints in both materials failed in the base metal. Fractures in the deoxidized copper were very near the joint interface, while those in the tough-pitch copper extended somewhat further into the base metal.

In the planning of the tests, it was thought that the eccentricity in the single-lap joint might affect a reduction in the strength of the joints. However, since the strengths obtained for the double and single joints were very nearly the same, it appears that the eccentricity in the joints had little or no effect upon the ultimate strength of the joints.

The fillet, however, had a considerable effect on the strength of the joints. This effect varied with the filler metal, but generally amounted to an increase of 20 to 30% in the ultimate strength. The increase, it must be remembered, is only for the specimens tested in this study and with a lap of approximately 0.150 in. The effect of the fillet upon another joint having a greater or lesser lap would be different depending on the length of the lap.

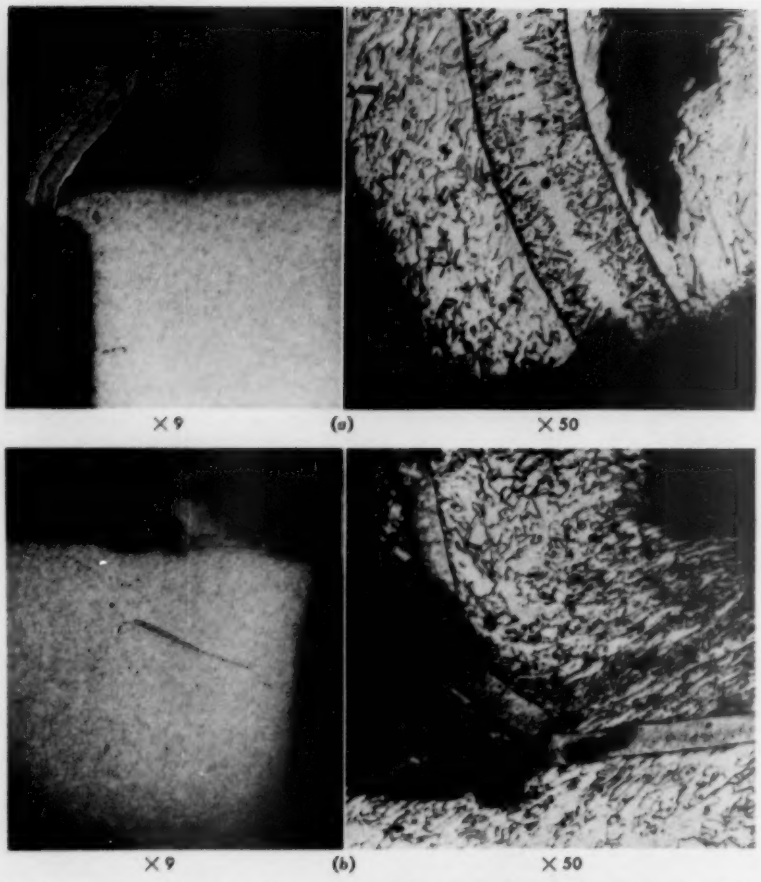

Fig. 9 Sections of fractured brazed lap joints in tough-pitch copper (reduced by 25% in reproduction). (a) BAg-1, filler metal. (b) BCuP-4, filler metal

Conclusions

From this limited study, it can be concluded that the filler metals investigated have strengths which are greater than that of the electrolytic tough-pitch or deoxidized copper, and that the brazing appears to reduce somewhat the strength of the base metal. However, even after brazing, the shearing strength of the base metal in a lap joint is approximately 60% as great as the tensile strength of the material, and the tensile strength of the material in a butt joint is about 90% as great as that of the original base metal.

To protect against a shearing failure in a lap joint, a lap of only $1^1/_2$ times the thickness of the material is necessary for a sound joint with fillets. If the fillets are removed, a lap of $1^3/_4$ times the thickness of the material, would be sufficient to develop the strength of the base metal. These lap lengths, however, apply only to a well-prepared and sound-brazed joint.

At a temperature of +400° F, brazed joints in copper may be expected to develop a shearing strength of approximately 10,000 psi in a sound joint. This strength is only 56% as great as the room-temperature strength, and, in addition, applies only to a short time loading—not to a long sustained loading in which creep might be an important factor.

At a temperature of −321° F, the strength of brazed joints in the deoxidized copper varied greatly with the various filler metals. However, the silver filler metals generally provided the greatest strength at this low temperature.

Acknowledgments

The tests described in this paper are part of an investigation resulting from a cooperative agreement between the Engineering Experiment Station of the University of Illinois and the Copper and Brass Research Assn. The work was done as a part of the Structural Research Program of the Civil Engineering Department, under the general direction of N. M. Newmark, Research Professor of Structural Engineering. The metal-

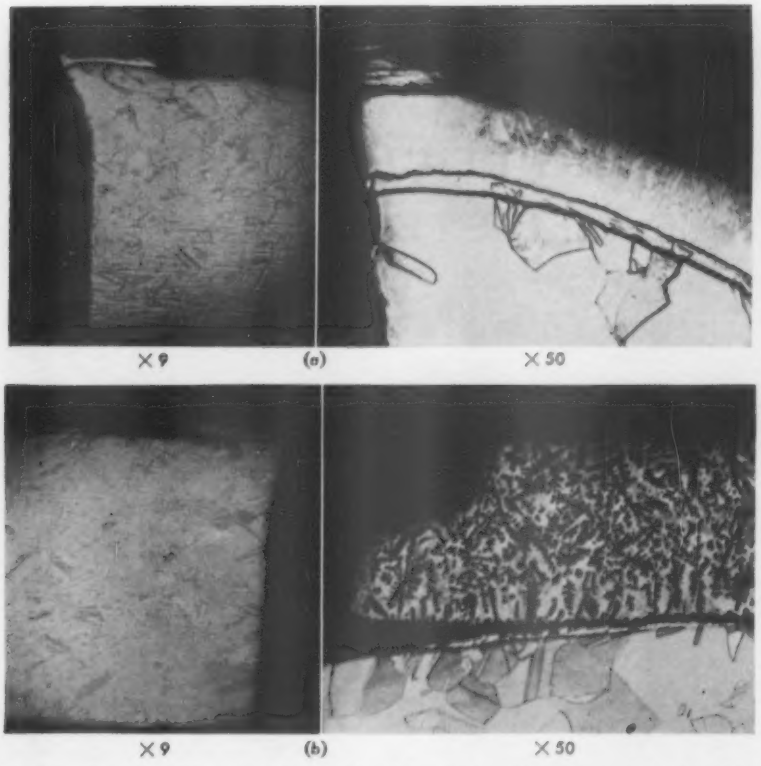

Fig. 10 Sections of fractured brazed lap joints in deoxidized copper (reduced by 25% in reproduction). (a) BAg-8, filler metal. (b) BCuP-5, filler metal

lurgical studies were conducted by Prof. R. W. Bohl, of the Department of Mining and Metallurgical Engineering, while the balance of study was conducted by D. C. Crawford, Research Assistant in Civil Engineering.

The assistance and advice of the Advisory Committee of the Copper and Brass Research Association is gratefully acknowledged. Their assistance in the planning of the program was invaluable.

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DISCUSSION BY KARL M. WEIGERT

In their presentation of tensile and shear strength in brazed copper joints the authors have shown that the fracture occurs in all cases in the parent metal and not in the brazed joint. This can be readily explained by the fact that the strength of most brazing alloys is considerably higher in the cast state than that of annealed copper stock.

The brazing operation was performed by a gas torch without data given on the exact temperature and time which influences not only the formation of the joint itself but also weakens the adjacent areas which consequently fail in the mechanical testing.

If the authors would conduct some additional experiments of heating unbrazed copper bars for various times and temperatures, both air-cooled and quenched, they most likely would find variations in tensile strength similar to the ones reported. In other words, the brazed joint did not enter the picture of the fracture mechanism. By prolonged heating at temperatures high enough to cause diffusion and alloying of the brazing alloy with the parent metal (copper) a fracture in the brazed joint might occur at somewhat higher values. It would be of practical value to develop such a technique.

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REPAIR WELDING

CONTINUOUS-COOLING TTT CURVES OF HIGH-TENSILE WELDABLE STEELS

BY F. NEHL AND A. ROSE

Continuous-cooling time-temperature-transformation curves have been useful in developing high-tensile steels in light and heavy sections for high-pressure boilers and chemical apparatus. An essential requirement of steel for this service is high yield strength at elevated temperatures, such as 650° F. Steels containing 1% copper have the desired high-temperature strength and must contain some nickel to avoid red shortness. The TTT curves of a copper-nickel steel are shown in Fig. 1. The curves show that the heat-affected zone of a weld in $3^1/_4$-in. plate contains no martensite or intermediate structure and would not have high strength.

Abstract of "Anwendung von Zeit-Temperatur-Umwandlungs-Schaubildern auf besondere Fragen bei der Herstellung Hochbeanspruchter geschweisster Bauteile," published in *Stahl u. Eisen*, **74**, 1054–1062 (Aug. 12, 1954). (Abstracted by Dr. G. E. Claussen.)

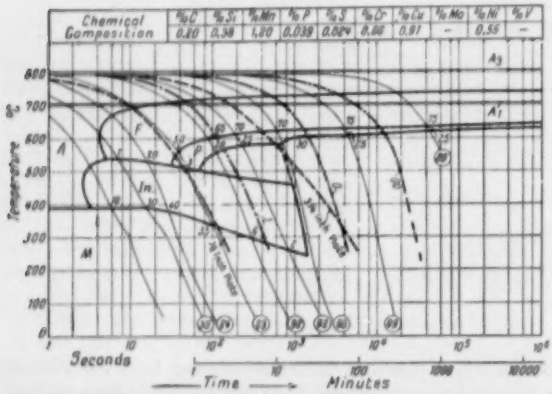


Fig. 1 Continuous-cooling TTT curves for a copper-nickel steel including cooling curves for different welds and different heat treatments

The TTT curves are based on austenitizing by heating to 870° C in 3 min and holding at that temperature for 8 min.
A **= austenite region;** ***F*** **= region in which ferrite forms;** ***P*** **= region in which pearlite forms;** ***In*** **= region in which intermediate structures form;** ***M*** **= region in which martensite forms; O = hardness values in Rockwell C and B.**
Small numerals are percentages of structural constituent. The cooling curve for $^1/_2$-in. plate was derived from thermocouple surveys by Nippes and Savage. The cooling curve for $3^1/_4$-in. plate was derived from thermocouple surveys of the heat-affected zone of a single-electrode submerged-arc weld in $3^1/_4$-in. plate. The thermocouple was $^3/_4$ in. from the fusion line at about mid-thickness. Cooling curve *L* applies to the air cooling of a 1-in. round from normalizing temperature. Cooling curve O applies to the air cooling of a drum $2^3/_4$ in. thick from normalizing temperature. Cooling curve OO applies to the furnace cooling of a drum $2^3/_4$ in. thick from normalizing temperature.

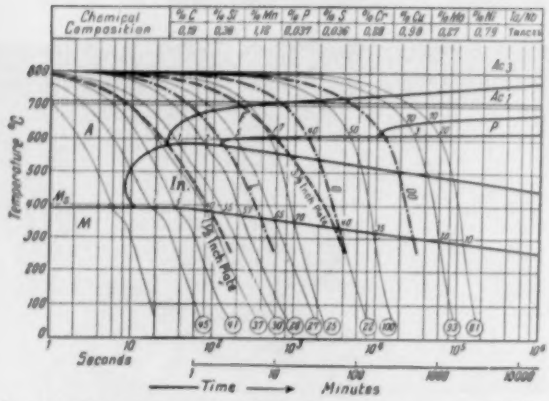
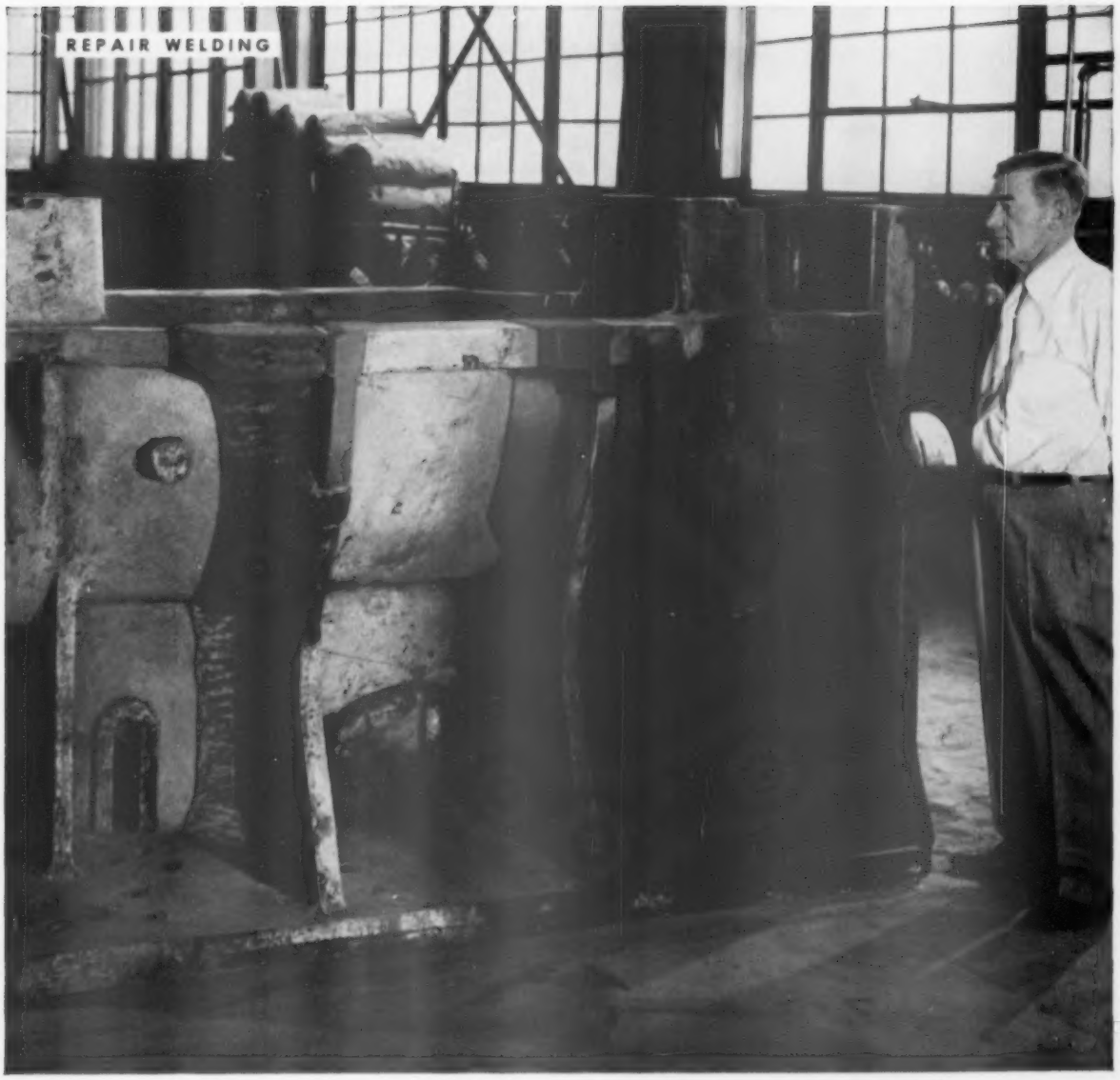


Fig. 2 Continuous-cooling TTT curves for a copper-nickel-molybdenum steel. The regions and cooling curves have the same significance as in Fig. 1

The strength of the copper-nickel steel can be raised considerably without increasing the tendency to weld cracking by adding 0.10% molybdenum and small quantities of carbide-forming elements. The TTT curve of such a steel is shown in Fig. 2. It is surprising that the region of intermediate structures extends to unusually slow cooling rates. The critical cooling rates in Figs. 1 and 2 are not too different. There is a great difference in the extent of the zone of intermediate bainite structures. In cooling from 800 to 500° C in 1000 sec the steel in Fig. 1 contains only 2% bainite, whereas the steel in Fig. 2 contains 70%. Raising the austenitizing temperature to 1050° C for the steel in Fig. 2 displaced the curves to the right, but did not alter the wide extent of the bainite region.

The curves in Fig. 2 show that the Cu-Ni-Mo steel will not be sensitive to underbead cracking, because at high cooling rates it transforms predominantly to bainite, not martensite. At low cooling rates, as in welding thick plates or during normalizing, the steel again transforms predominantly to bainite instead of to low-strength ferrite and pearlite. The yield strength of a steel containing 0.21 C, 1.34 Mn, 0.51 Si, 0.23 Cr, 1.10 Cu, 0.34 Mo and 0.98 Ni was 77,000 psi at 68° F and 72,500 psi at 660° F. The tensile strength was 100,000 psi at these temperatures. These properties were developed by normalizing (cooling rate 18° F per minute) followed by stabilizing for 5 hr at 1100° F, followed by air cooling.



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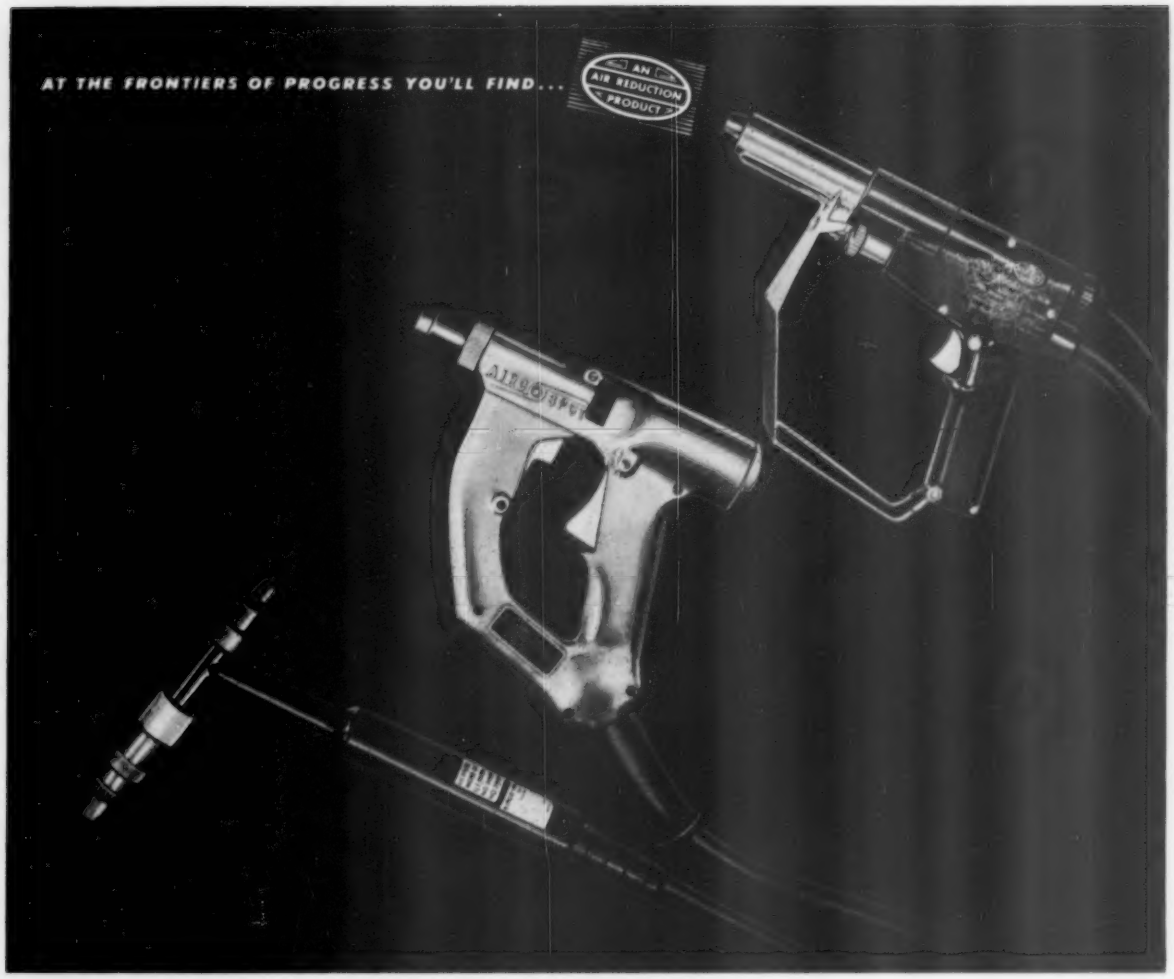

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